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STONE OBSERVATORIES IN INDIA

Erected by Maharaja Sawai Jai Singh of Jaipur

(1686-1743 A. D.)

at Delhi, Jaipur, Ujjain, Varanasi, Mathura

Prahlad Singh

Assisted by

Pandit Kalyan Dutt Sharma, Jyotishacharya
Former Supervisor, Jaipur Observatory

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Dedicated to

the inspiring memory of

MAHARAJA SAWAI JAI SINGH–II

of Amber and Jaipur

(1686 - 1743 A. D.)

Who created the magnificent

Stone Observatories in India

MAHARAJA SAWAI JAI SINGH-II

—Courtesy, Maharaja Sawai Man Singh II Museum Trust, Jaipur.

Rajmahal, Jaipur
Rajasthan

FOREWORD

Maharaja Sawai Jai Singh II (1699-1743) was a very remarkable ruler. It was during his time when India of the time was passing through its darkest hours—the Moghul empire was crumbling under the pressure of internecine wars and the conditions in the country were most unsettled. One would wonder how he could function at such a time not only as a ruler but also as an Astronomer, Scholar, Scientist, Mathematician and Town planner while most of the time, he himself was involved in these wars.

We learn from the contemporary historians that Maharaja Sawai Jai Singh II lived during a period following Aurangzeb's death which brought in its wake disruption and tumultous wars. His help was sought by the one who sought to protect his throne and the one who wished to grab it and he did always have a part to play in these dramas. One only wonders how he could concentrate his energies and mind at such a time to a science, a delicate science, such as astronomy. In those uproarious days, he built not only one but five Astronomical Observatories—at Jaipur, Mathura, Delhi, Banaras and Ujjain. I commend the effort of the author to bring out this book so that more people know more about the unparallelled standing monuments contributed by my illustrious ancestor to Science.

The world, since the conception and construction of the Astronomical Observatories, has gone through a scientific

revolution but the fundamentals of the Observatories have remained unchanged and stood the test of time - they have not been reduced to mere stone slabs and zig-zag designs—their function still remain the same today as when they were conceived and constructed.

The cultural renaissance of this country with its rich heritage can only be fruitful if our research scholars probe deeper into the past in a scientific manner and make our contribution in the field of arts, learning and sciences more widely known to the world.

JAIPUR
December, 1972.

(MAHARAJA OF JAIPUR)

PREFACE

My love for astronomy sprouted in my childhood. My grand-father Thakur Jai Singh of Chandana (not to be confused with the astronomer–Maharaja of Jaipur), often baffled me by telling the correct time by looking at the Sun and certain prominent stars and asterisms. He used to narrate astronomical legends and the courses of different heavenly bodies, while I had long horse and camel rides with him through the sanddunes of Shekhawati (North-Eastern Rajasthan) where the sky is brightly clear almost round the year. He also taught me to recognise some of the celestial spheres and their placements from the terrace of our fortress at Chandana. Then there was the village astrologer who would look into his 'Pañcāṅga' (ephimery), do some quick calculations and announce auspicious timings for marriage, travel, business deals, holy fasts and festivals, and even for sowing the fields. Always sought-after by people, he would predict the future by the horoscopes and forecast the eclipses and the advent of sand-storms and rains based on the transition of stars and planets. All this aroused in me a great curiosity to probe into the ways and means of the ancients in the sphere of observational astronomy.

Then there was long intermission until it fell upon me to escort a group of foreign-visitors to the Jaipur Observatory. I was to comment upon the entire fairy-land-like complex, consisting of various odd-shaped massive structures built in apparently ultra-modern style of architecture. Everybody seemed to be puzzled and lost. Here it was that I found myself interested in discovering what observational astronomy really was. Thence began my long research in the realm of the "Stone Observatories in India."

Having spent years together under the lengthening shadows of the gigantic instruments of these magnificent observatories, I was overpowered by the scientific nature of their principles and imposing constructions. Another factor responsible for the outcome of this book was the great sense of admiration and the childlike curiosity I so very often witnessed in the eyes of many visitors who heard my commentaries in the sprawling premises of these royal observatories. Their constant queries about the principle of construction, purpose and the method of observation of the various instruments inspired me to probe deeply into the origin, conception and development of various 'Jyotiṣa Yantras' of Maharaja Sawai Jai Singh of Amber and Jaipur (1686-1743 A. D.) who is accredited with being the only astronomer in the world to have erected as many as five astronomical observatories. It is interesting to know that to execute this scientific grand plan he chose five most suitable sites in the country from political, academic and religious points of view—Delhi, Jaipur, Ujjain, Varanasi and Mathura.

The book does not claim to be a treatise on astronomy, but it certainly deals with the unique subject of the 'megalithic' observatories in India. It briefly discusses the history of Hindu astronomy, describes the contribution of the astro-scholars of the antiquity, viz., Āryabhaṭa, Varāhamihira, Brahmagupta, Bhāskarācārya and a host of others who preceded Maharaja Sawai Jai Singh, to the science of astronomy in the country. It also traces the origin and development of various astronomical devices through the ages till they attained perfection and found their eternal place in various observatories set up by the astronomer-prince of Jaipur. The book describes in detail how a particular instrument is constructed, how it is to be used and what calculations can be derived out of it during day and night as people in general intend to know. I have tried to simplify the technical aspects of the instruments for the benefit of the readers.

These magnificent stone observatories are the prestigious monuments of the rich classical heritage of the nation and are regarded as unique in the world. The kaleidoscopic shapes of these massive stone and masonry instruments have been described "the most surrealistic and logical landscape in stone in the world."

Though meant for the naked-eye observations two and a half centuries ago, these observatories are much more frequented by people than any modern observatory in the world. They have become the national monuments of tremendous historical, scientific and educational significance and thus, deserve to be protected by all means. There cannot be a better way of paying homage to the genious of the great astronomer-Maharaja for this monumental contribution to the nation than by maintaining and preserving these "out-of-this-world" observatories in their original shape.

It is heartening to know that M/s. Bharata Manisha of Varanasi have decided to publish the scientific achievements of Maharaja Sawai Jai Singh to coincide with the 250th Anniversary of his another great creation, the marvellous City of Jaipur.

Prahlad Singh

JAIPUR

June, 1977

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I am grateful to Pandit Kalyan Dutt Sharma, Jyotisha-charya', former Supervisor of the Jaipur Observatory, who assisted me in understanding the technical aspects of the subject and the Sanskrit texts which I had to consult for my extensive research. I also wish to thank Pandit Kamalakant Joshi 'Jyotishashastra-charya', Superintendent, Ujjain Observatory; and Pandit Prem Das, Supervisor, Delhi Observatory with whom I had very useful discussions on the subject. The members of the staff of these observatories proved extremely cooperative and helpful whenever I visited them for my studies and observations.

My correspondance with the National Geographic Society Washington, D.C.; the International Astronomical Union Commission on the History of Astronomy, Cambridge, Mass., U.S.A.; the Journal for the History of Astronomy, Cambridge, England and Royal Astronomical Society, London also proved very informative.

I am greatly indebted to my friend, Mr. Harsh Vardhan who went through the script carefully and critically and made various suggestions to finalise it. My thanks also go to my former lecturer Mr. A. L. Shah of the Department of English, Rajasthan University, Jaipur and Mr. N. K. Pareek, Deputy Director, Rajasthan Public Relations Department, Jaipur, for going through the manuscript. I extend my sincere gratitudes to Shri Bansi ji, State Photographer Jaipur, for taking most of the illustrative photographs for the book and to Shri Arjun Lal for typing out the matter.

I greatly appreciate the help and encouragement I got from my many colleagues and friends. They include, to name a few, Shri Jai Singh Bika of New Delhi; Shri U. P. Sahi of Varanasi; Sarvashri B. N. Kaushik, R. G. Sharma and Ganpat Singh of Jaipur; and Mr. Harrison Shields of the Ask Mr. Foster Travel Service of the U.S.A.

When I was in France on an invitation of the Jet Tours, Paris, the friends who took interest in the publication of this work, include Monsieurs Steve Lecler, Vincent Borel, Michel Thomin Mmes Caroline Aubry, Regine Meyer; Mlles Claudine Mathe and Paule Viallard among many others.

CONTENTS :

CHAPTER 1

BRIEF HISTORY OF ASTRONOMY IN INDIA

Astronomy, the science of astral luminaries, is regarded as the most ancient science in the world. As astronomy is symbolic of man's curiosity about nature, its origin took place during the dark ages of human civilisation, which is hidden under the avalanche of time. The earliest man must have been an observer. This primitive observer was wonder-struck at the rapidly changing phenomena of nature. He was enthralled to see the bright sun and fascinated to watch the shining moon and the innumerable glittering stars in the sky. He was, sometimes, awe-struck to see the eclipsed sun and the moon and the shooting stars. The striking spectacle of nature, thus, attracted the human attention in the remotest period of our history.

The numerous stars of different magnitude, the daily changing phases of the moon, the phenomenon of day and night and the changing seasons raised strange feelings for the man when he was still dwelling in the caves. He had mixed feelings of admiration and awe. All this happened before the development of an adequate language to express himself. The cave-dweller was evolving the reason. His notions about the astral events also developed slowly. He would have taken a long time to express his ideas formed by observations. A gradually developed language gave birth to the exchange of ideas. And thus started the process of the evolution of astronomy.

The origin of astronomy in India is as old as any school of astronomy in other ancient civilisations and it has maintained

its originality through the ages. India has been a country of the hermits, sages and mystics. They spent all their life in meditation to attain the salvation and eternal peace, better known as the 'nirvāṇa'. They also contemplated on the subjects like religion, philosophy and astronomy. Later Brahmin priests preached and taught these subjects to the people. This gave birth to the 'Guru-śiṣya' (Teacher-Taught) tradition. Teaching was verbal and the disciples learnt astronomy by heart. Sky and the heavenly bodies were observed by the Gurus for instructing the inquisitive disciples.

The astronomical thought continued to progress in purely dialogue form until the writing started. The knowledge further expanded in this manner as it was extensively debated, put to test and verified in a larger periphery of experts. The road to astronomy was thus paved with gradual experiments, conclusions of which continued to be like the game of 'hide and seek' for the experts. Despite myriad changes in today's metaphysic set-up all the highly scientific discoveries have not been able to rebut the ancient Indian beliefs. And so stand the five wonderful Observatories today, justifying the nation's astronomical pursuits in the days of yore.

The Vedic Era

The Vedas are the very first literary works on philosophy and religion of the Āryans and are regarded as the first handwritten manuscripts in the world. The Vedas—the books of wisdom are four, viz., the Ṛg-Veda, the Yajur Veda, the Artharva Veda and the Sāma Veda. They are supposed to date back between 4000 and 2500 years B. C. though they existed much earlier in verbal form. The Vedas are not any treatises on astronomy but they give a detailed account of astronomical beliefs and practices of the ancient Āryans.

Astronomy was studied in the Vedic period as 'Nakṣatradarśa' appears in the Yajur Veda. 'Nakṣatradarśa' literally means

an astronomer as 'Nakṣatra' means a star and 'darśa' means an observer or a gazer. One comes across 'Nakṣatravidyā', meaning the science of stars or astronomy, in many references. 'Jyotiṣa' which literally means the science of the luminaries, was considered as one of the six 'Vedāṅgas' or limbs of the Vedas.

Religion and a tronomy had become inseparable during the Vedic era. The Vedic priests and preachers taught astronomy also. Sacrificial rites were performed in accordance with the position of the moon which was observed by Brāhmaṇa-astronomers with reference to lunar asterisms. They observed the Sun's annual course to regulate their religious activities. Sun's northern course (Devāyana) was considered more auspicious than its southern course (Pitrāyana) for performing the rites and rituals.

The Vedic priests had started making astronomical observations of the starry sphere. This was the 'Stone-age' of astronomy as they had no sophisticated appartus. They studied heavenly bodies and explored the mysteries of the universe with their unaided eye. These naked-eye observers who were the inspired and enlightened sages, undoubtedly utilised their power of 'Yoga' and meditation to form a clear concept of the universe and it luminaries.

The Ṛg-Veda deals with principles of asterisms. The asterisms were distinguished from the stars as a group of stars that would fall on the Path of the moon. 'Nakṣatras' (asterisms) were regarded as twenty eight though only twenty seven of them occur in some references in the sacred texts. Abhijit (Lyri Vega) was acknowledged as the twenty eighth asterism. Their list of twenty eight 'Nakṣatras' was headed by the Kṛttikās (Tauri Pleiade) which marked the vernal equinox of the Vedic year. This is considered as the foundation of the Vedic chronology by some scholars who fix this time as 2350 B. C.

These visionary ancient recognised some other groups of stars by constant observation of the starry sphere. 'Sapta Ṛṣi' or the Seven Sages (Ursa Majoris) was one of them. The Hunters' 'Bṛhat Lubdhaka' (Canis Major) and 'Laghu Lubdhaka' (Canis Minor) were discovered as situated east of the 'Mṛga' (Sirius) and on either side of the 'Ākāśa Gaṅgā' or the Celestial Ganges (the Milky Way). 'Divya svāna' (Celestial Dogs), 'Divya Naukā' or 'Nau' (Celestial Boat or Navis) and 'Nakṣatriya' Prajāpati (Aurigal) were described in the Vedas.

The Vedic teachers had evolved a distinct system of chronology. They had their own calendar which they followed for their mundane activities. The Vedic year consisted of twelve months. Solar year, lunar month and terrestrial days were in vogue. A thirteenth additional or intercalary month (Adhikamāsa or adhimāsa) was added to a year after almost every third year to adjust the lunar months with the solar year. This was done to make the seasons appear at about the same months of the year. This Vedic practice is still followed by the Hindu astronomers for making calendars. The 'Kṣayamāsa' or the delatory month also existed in their chronology.

The average length of their lunar month was 29.53 days. 'Aitareya Brāhmaṇa' mentions 360 days in a year. The month was divided into two 'Pakṣas' or parts, viz., Kṛṣṇa Pakṣa (the dark part) and Śukla Pakṣa (the light part). This was based on the phases of the moon which was being distinctly observed by the Vedic masters of astronomy. The 'Pakṣa' consisted of about fifteen 'tithis' (lunar days) which were counted according to the phases of the moon. Even the day was subdivided into forenoon, mid-day and after noon.

The ancient Indian astronomers had evolved the names of six seasons and twelve months the earliest in the world. They named their lunar Months on the basis of the rising and setting of the 'Nakṣatras' (asterisms) at a regular interval. The Kṛttikās

(the Pleiades) were observed to rise at the east point of the horizon as they believed that the Pleiades did not deflect from the east.

The asterisms could be spotted on the eastern horizon after sun set on the full moon night. It marks the end of a month. As an example, Citrā Nakṣatra (Virginis spica) rises on the eastern horizon after the sun-set on Caitra Śuklā Pūrṇimā (the full moon night of the month of Caitra) and this would mark the end of the month of Caitra, as shown in the following table :

Name of the Hindu Months	**Names of their respective Nakṣatras (asterisms)**
1. Caitra	Citrā (Virginis spica)
2. Vaiśākha	Viśākhā (K. Librae)
3. Jyeṣṭha	Jyeṣṭhā (Scorpionis Anteres)
4. Āṣāḍha	Pūrvāṣāḍhā (Sogittari)
5. Śrāvaṇa	Śravaṇā (Aquitae, Altair)
6. Bhādrapada	Pūrva Bhādrapada (Regasi-Markale)
7. Āśvin	Aśvinī (Arietis B. Arietis)
8. Kārtika	Kṛttikā (Tauri Pleiades)
9. Mārgaśīrṣa	Mṛgaśirā (Orionis)
10. Pauṣa	Puṣyā (Cancri)
11. Māgha	Maghā (Leonis Regulus)
12. Phālguna	Pūrva Phālgunī (Leonis)

Many myths and legends about the astral luminaries and earth were in vogue which popularised astronomy among the masses. But it was believed in general that there was only one Sun in the Universe and it caused the change of seasons. 'Taittirīya Saṁhitā' mentions the Sun as the 'Sapta-Raśmi' which means that the Sun has seven rays. It suggests that the ancient Indian scholars were familiar with seven colours of the spectrum. The same 'Saṁhitā' states about the moon that it shines due to the light of the Sun as it is termed as 'Sūrya Raśmi' or the rays

of the Sun. The moon was believed to live among the stars. Another religious text 'Aitareya Brāhmaṇa' states that the earth is round. It is separated from the sky and is suspending in the universe without any base.

It appears that the Vedic poets had more than elementary knowledge of the planets and their astral placements. The five known planets were named as Maṅgala (Mars), Budha (Mercury) Bṛhaspati (Jupiter), Śukra (Venus) and Śani (Saturn) and regarded as gods. The Sun and the Moon were also worshipped. The three planets Naptune, Uranus and Pluto, lately discovered by the European astronomers with the help of the telescope, were referred in the Ṛg-Veda as Aryamā, Varuṇa and Ritta respectively. In his 'History of Indian Literature' Prof. Weber writes that the Hindus had a vast knowledge of their own of the stars and planets and they had also developed a systematic luni-solar calendar.

It is interesting to know that the science of mathematics evolved round the 'Yajñas' in ancient India. Instructions are given in the Ṛg-Veda for making the 'Vedis' (altars) for performing religious rites and rituals. B. B. Dutta, mentions in his 'Science of the Shulba' that these altars could be correctly prepared only by following the rules of geometry and algebra. Only the scholarly Brahmins could make them. Thus, the geometrical application of algebraic equations was in use to some extent in the Vedic times. Another ancient treatise 'Śatapatha Brāhmaṇa' (2000 B.C.) also gives similar instructions for making the altars for 'Yajñas' and worship. These rules were compiled by the astronomer-sages in the 'Śulba Sūtra' between 800 and 500 B. C. Astronomy was, thus, flourishing in ancient India and its advancement continued steadily in the following generations.

CELESTIAL OBSERVATIONS :

There is no evidence of the use of any astronomical apparatus as such for ascertaining the movement of astral bodies in

the Vedic period. The only vague reference in the Ṛg-Veda is about an instrument called the 'Śaṅku' (the gnomon) which was initially used to determine the four directions. The astro-scholars solely dwelt upon this device as knowing of correct directions was a pre-requisite for performing the 'yajñas' and other religious ceremonies. No precise description of this primitive instrument is available. It is believed, however, that the 'Śaṅku' helped the scholars to know the time also as it served as a Sun-Dial in its primitive form. The 'Śaṅku' was placed at the centre of a circle drawn of any radius. The shadow of the 'Śaṅku' at mid-day would demarcate north-south. When the shadow would be smallest it would be mid-day.

The observation of the 'Pūrṇimā' (the full moon night of the month) and the 'Amāvasyā' (the darkest night of the month) and the rising and setting of the 'Nakṣatra ' was also significant for the purpose of certain astronomical observations and calculation .

The Rāmāyaṇa and the Mahābhārata Period :

The Rāmāyaṇa is the epic story of Lord Rāma, the king of Ayodhyā and his victory over Rāvaṇa, the notorious king of Laṅkā. This great Hindu epic is believed to have enacted sometime between 2500 and 2000 B. C. though some scholars believe it to be much older than that.

The Vedic traditions of astronomy were being followed during the Rāmāyaṇa period. Maharṣi Vālmīki, the author of the Rāmāyaṇa mentions in the epic about the stars and planets and their movements. The astronomers devoted themselves to the study of the influence of the heavenly bodies on human lives and consequently astrology began to have great impact on the minds of people. Astrologers were consulted to calculate and predict the auspicious hour for various social and political activities. The placements of the stars and planets were observed

and calculated for astrological interpretations. The horoscopes were also cast. Vālmīki gives the details of the horoscope of Lord Rāma in the Rāmāyaṇa. Lord Rāma was born at mid-day on the caitra śukla Navamī (the nineth day of the light part of the month of caitra) in Pauṣyā Nakṣatra (Cancri asterism) and under the Karkaṭa Lagna (Cancer ascendant). It also indicates the positions of five planets: the Sun, Venus, Mars, Saturn and Jupiter at the time of his birth. This clearly indicates that the astronomers of the Rāmāyaṇa period observed the positions of the asterisms and planets and were well acquainted with the zodiac ascendants.

Rāvaṇa, the king of the demons of Laṅkā was an eminent scholar of astronomy and astrology. His work the 'Rāvaṇa Saṁhitā' is still available in India. Other prominent scholars of this era were Vaśiṣṭha, Viśvāmitra Manu and Yājñavalkya. The 'Yājñavalkya Smṛti' of sage Yājñavalkya has references of stars, asterisms and their various groups. It describes twelve equal parts of the ecliptic. Auspicious astral positions of the luminaries are given for performing rites and rituals. Similar references occur in another sage Manu's 'Manu Smṛti', a well known ancient work on human conduct and ethics. Sage Manu described and defined different cycles of time in the names of 'Yuga' and 'Kalpa'.

The Mahābhārata is another Hindu epic describing the great war fought between two cousins, the Kauravas and the Pāṇḍavas. It is believed to have happened not after 1531. B. C. though the opinions of the scholars differ. Balkrishna Dixit states that this period could be as old as 3078 B. C.

The astronomers of this period described the system of chronology by 'Yugas' which were considered five, viz., Satā Yuga (17, 28,000 years), Tretā Yuga (12,96,000 years), Dvāpara Yuga (8,64,000 years) and Kali Yuga (4,32,000 years). This

reference of duration of different 'Yugas' leads to the eternity of time. A five year 'Yuga' was also mentioned. Lunar days, omitted lunar days ('tithikṣaya') and intercalary months were used for their systematic calendar.

Astrology had become popular and hence the astronomers studied the astral positions to determine and predict the auspicious time for coronations, marriages, travels and even wars. Horoscopes were cast and future events predicted in accordance with the astronomical placements of the heavenly bodies. Yudhiṣṭhira, the eldest of the Pāṇḍavas was born at mid-day on Aśvin Śuklā Pañcamī (the fifth day of the light part of the month of Aśvin). His horoscope further states that he was born on Monday in Jyeṣṭhā Nakṣatra (Scorpionis Anteres asterism). He was scorpion. The astronomers had, thus, an extensive knowledge of planets, asterisms and the zodiac circle. By constant observation of the sky, they had become acquainted with the comets and meteors, Sun's annual course, the precession and twenty seven asterisms. They associated twenty seven gods with asterisms and worshipped them, thus, combining religion with astronomy.

The Mahābhārata has frequent references to week, seasons, caitra and other eleven months and the solar and lunar eclipses. It states that a lunar eclipse took place on the 'Pūrṇimā' (the full moon night) before the epic battle started. A solar eclipse followed the lunar eclipse within fifteen days in the same month of Kārtika. Both these eclipses were seen from a place named Kurukṣetra, near Delhi, where the devastating war of the Mahābhārata was fought. This was a rare astronomical phenomenon to see both the eclipses in the same month and from the same place. This was regarded as an utterly bad omen by the astrologers. They predicted unprecedented disaster and calamity which turned out to be true as hundreds of thousands men were

killed and two great dynasties perished in the epic battle of Mahābhārata.

The names of five planets appear in the Mahābhārata. Seven planets are also mentioned elsewhere in the epic. They include Rāhu (the Ascending Node) and Ketu (the Descending Node). Both Rāhu and Ketu could not be spotted by the naked eye but their positions could be determined by eclipses. The astronomers of this period have made frequent references to these planets clearly proving that they had profound knowledge about even such invisible astral bodies. They knew about the real causes of eclipses and could pre-determine their correct time. Mean motion of the planets like Jupiter and others were known and their retrograde motion, their rising and setting was observed. Sun was regarded as the cause of rains. Tides were believed to be caused due to the moon. Earth was considered to be round and it was known that the back of the moon was never visible. Maharṣi Garga was a famous astronomer of this period who is quoted time and again in the epic.

Some scholars are, however, of the view that the reference to zodiac signs and their ascendants in the epics is the result of later additions. They hold the view that the Hindus came to know about the zodiac signs and their ascendants after the Rāmāyaṇa and Mahābhārata period.

THE DAWN OF HINDU ASTRONOMY : 1500-850 B. C.

Vedāṅga Jyotiṣa :

The 'Vedāṅga Jyotiṣa' is the first systematic book on the Hindu astronomy. This also happens to be the first ever work on astronomy written in human literature. It was composed by Maharṣi Lagadha who probably hailed from Kashmir sometime between 1400 and 1200 B. C. Opinions about its correct period, however, differ. Prof. Max Müller considers it about 300 B. C., Colebrooke, 1410 B. C. and Prof. Whitney, 1338 B. C. According

to the precession of the equinox, as mentioned in the treatise, this period comes to 1408 years B. C.

The 'Vedāṅga Jyotiṣa' consists of three treatises on Hindu astronomy viz., the 'Ṛgveda Jyotiṣa', 'Yajurveda Jyotiṣa' and the 'Atharvaveda Jyotiṣa'. The first two mainly deal with astronomy while the last one is an exclusive treatise on astrology.

During this period (1500-850 B. C.) the Indian astronomers could determine and compute the placements of the Sun, the moon and the planets. The moon's position was determined among the stars. The orbit of the moon was divided into 27 equal parts, each known as the 'Nakṣatra' or the asterism. The zodiac circle was rearranged and divided into 27 'Nakṣatras' of (360/27 =) 13 degrees 20 minutes each. In other words, the astronomers arranged the asterisms to tally more nearly with the moon's daily mean motion. Likewise the ecliptic was divided in twelve signs of the zodiac of 30 degrees each. These signs were used for indicating the positions of the celestial bodies, which were used for making the calendars and almanacs. The positions of the moon in its particular asterism on the full moon night and the darkest night of the month were observed by the astronomers. Rules were also given to determine the celestial equator and the equinoctial day. Addition of the longitudes of the Sun and the moon was done for astronomical calculations. The phases of the moon were observed. The master planets of the week and deities of 27 Nakṣatras' were also named.

They evolved a definite cycle of time which they followed in their luni-solar calendar. A 'Yuga' consisted of five years of 62 luner months of 29.56 days each or 1830 days and nights. The treatise gave the duration of each Yuga, the number of rising of the stars in a 'Yuga', two intercalary months to be added in one 'Yuga', the position of the Sun and the moon at the beginning of a 'Yuga' and the beginning of the southern and the northern course of the sun. It clearly stated that during the Sun's northern

progress, the length of the days increases and every day is of more than thirty 'ghaṭikas' (twelve hours) duration, on the contrary, during the Sun's southern progress, the days decrease and are always less than 'thirty ghaṭikas' (twelve hours) duration.

Thus, during the Jyotiṣa Vedāṅga period, the ancient Hindu astronomers had started minute observations of the steller sphere, its luminaries and their movements. They could determine the true positions of the planets and asterisms to a commendable degree of accuracy. They had evolved rules for preparing their luni-solar calendar based on three natural units of time, viz., day and night, lunar month and solar year. The same rules are followed by the astronomers to make the Hindu calendars even today.

Between 1000 B. C. to 400 A. D. the Indian astronomers had two beliefs about the earth and the motion of the planets. According to one, the earth was the centre and other planets revolved around it due to the 'Pravahavāyu' (the aerial fluids). The second belief was that the planets were revolving around the Sumeru Mountain in the natural course.

Maharṣi Lagadha laid the foundation of systematic astronomical calculations. 'Gaṇita' the science of calculations, was in vogue for astronomical studies. About 'gaṇita', the Vedāṅga Jyotiṣa states : 'just as the crest is to the peacock, and just as the headgem to the snake, so the 'gaṇita' among the Vedāṅga Śāstras stands at the head." The terms, jñeya and jñāna rāśis (the unknown and known quantities) occur in the 'Vedāṅga Jyotiṣa' for the first time in the history of mathematics. Thus, mathematic was used for astronomical studies and additions, subtractions, multiplication and division of numbers and the rule of three were known to the 'Vedāṅga Jyotiṣa' astronomers.

ASTRONOMICAL INSTRUMENTS :

There is no explicit reference to astronomical instruments in the 'Vedāṅga Jyotiṣa'. The 'Śaṅku' was, however, used for

determining time. Astral placements of the stars and planets were also measured by placing the gromon in different planes.

According to G. R. Kaye, the only instrument of practical utility for astronomical purposes described in ancient Hindu works are the Sun-Dial and the Clepsydra. Of the two, the Clepsydra, consisting of a metal bowl floating in a vessel of water, was of more utility. The Clepsydra was also known as the Water-Clock. The amount of water that measures a 'nadikā' (24 minutes) was given. The more ancient form of Water-Clock appears to have been simply a vessel with a small orifice at the bottom through which the water dripped in a 'nadikā' (vessel).

Eighteen Ṛṣis (Sages) were prominent astro-scholars in ancient India before the beginning of the Christian era. They were Sūrya, Paitāmaha, Vyāsa, Vaśiṣṭha, Attri, Parāśara, Kaśyapa, Nārada, Garga, Marīci, Manu, Agara, Lomeśa, Pauliśa, Cyavana, Yavana, Bhṛgu and Śaunaka. Their works were known as 'Siddhānta', 'Saṁhitā' or 'Smṛti'. The most important of these are the 'Sūrya Siddhānta' on astronomy and the 'Bhṛgu Saṁhitā' on astrology.

500 B. C.—500 A. D. :

ASTRONOMY IN JAINISM AND BUDDHISM :

The philosophies of Jainism and Buddhism started sweeping across India from the fifth century B. C. onwards. The Jain and Buddhist scholar-monks wielded great intellectual and philosophical impact on the minds of people but they did not, however, make much headway in astronomical studies. After the 'Vedāṅga Jyotiṣa', some treatises were written by Jain scholars between the fifth century B. C. and third century A.D.. The well-known independent works on the Jain astronomy were the 'Sūrya Prajñapti', 'Jambū dvīpa Prajñapti' and 'Jyotiṣa Karaṇḍaka'. The Jain astronomer-monks believed that the Sun

and the planets were circling around the Sumeru mountain. The Sun's annual course was divided into northern and southern courses. The elements of mythology were prevalent in the Jain treatises as two sets each of the Sun, the moon and the constellations were believed to be circling around the Sumeru mountain in rotation. The five year cycle of the 'Yuga' was considered to begin with the summer solstice with the Sun in the Cancri asterism which was a correction from the 'Vedāṅga Jyotiṣa' belief. Another point of difference with the older belief was the employment of twenty eight 'Nakṣatras' of unequal extent which altered, somewhat theoretically, the positions of the asterisms. Thus, the followers of the philosophy of Jainism did not make real advancement in the field of astronomy.

There are no explicit astronomical references in the Buddhist treatises as the Buddhists were totally against astrology and partially against astronomy. These subjects were considered as mean by the Buddhists. They believed that the earth was suspending in the universe and that it could fall any time as it had no base. They strongly criticised the Hindu astrologers contemplating on omens and their forecasts. Astronomy and astrology were considered as misleading the masses by the Buddhist monks and scholars who devoted themselves to deep meditation to attain the 'nirvāṇa' (salvation). Astronomy is severely criticised in a Buddhist work entitled the 'Lavaṇa Muṣṭi', literally meaning the 'handful of salt'.

Kauṭilya's Arthaśāstra :

The 'Arthaśāstra' (The Economics) of Kauṭilya (Cāṇakya) written around 300 B. C. was a famous book of its time. It is still regarded as a base for the state economics and public administration. Though it is not a work on astronomy, it gives some details of this science of that period. It states that Hindu astronomers were well-versed in astronomical and mathematical calculations. Astrological forecasts were made. The vibration

of different limbs of the body and the dreams were astrologically interpreted. Celestial positions were studied for predicting weather, natural calamities, epidemics etc. The sky was constantly observed by the astrologers to predict auspicious hour for various social activities and ceremonies. Forecasts about crops and famine were frequent. The emphasis was on astrology and astrologers were patronised by the kings for consultations. There was, however, no significant progress of the science of astronomy during this period.

No complete record of astronomical study and research between 500 B. C. and 500 A. D. is available. The records were either destroyed or lost. This was a period of upheaval. Wars had become frequent. Alexandar, the great Greek, invaded India and conquered a part of it. This strengthened the Indo-Greek contacts which had already begun. The contact between two great civilisations resulted into mutual exchange of ideas and techniques in drama, literature, architecture and of course, astronomy, as mentioned later. After the fifth century A. D. some prominent Hindu astronomers came on the scene and by their constant research and missionary zeal they took this science to Olympian heights.

THE ANCIENT HINDU LUMINARIES :

Āryabhaṭṭa I :

Āryabhaṭṭa I, one of the most prominent Hindu astronomer, mathematician, was born in 476 A. D. in Kusumpur near Patliputra (modern Patna) which was a great seat of learning in ancient times. Āryabhaṭṭa I was the most celebrated astronomer of the Gupta period (300-600 A.D.). His masterpiece on astronomy and mathematics is entitled as the 'Āryabhaṭīya' (Āryabhaṭāyam in Sanskrit) written about 500 A. D. His other, two well known works are the 'Tantra' and 'Daśa-Gītikā'. He was the first Indian astronomer to deal with astronomy as a science.

A great thinker and researcher of his times, Āryabhaṭṭa I became the pace setter of Hindu astronomy when he set ablaze a fresh thinking about the earth and the astral bodies. He was the first Indian astronomer to spark off the theory of the diurnal motion of the earth on its axis causing the phenomenon of day and night. He discovered that the astral bodies like the Sun and the stars were immovable. In his own words : 'The sphere of the stars is stationary and the earth making a revolution produces the daily rising and setting of stars and planets''. He explained his belief in the 'Āryabhaṭīya' as, "Even as a man seated in a boat perceives the trees on the banks to go in the opposite direction, just in the same way, an observer perceives the stationary stars as though coursing towards the west.'' This was a bold new discovery which shook the whole foundation of many a century old astronomical belief of a stationary earth. It startled the astronomers of his age. His theory shattered the false conceptions of the previous generations of mankind and revolutionised the study and research of astronomy in India. However, the discovery made by Āryabhaṭṭa was not accepted by the prigs and puritans after his death and the Indian astronomy remained confounded to the same old belief of the astral bodies revolving round a stationary earth. Had Āryabhaṭṭa's theory of the earth's daily rotation on its axis been accepted by the Indian astronomers, the shape of the Hindu astronomy and its history would have altogether been different. After nearly a thousand years, the soul of Āryabhaṭṭa I was reincarnated in Nicolaus Copernicus (1473-1543 A. D.) who advocated the same theory which, after a strong Catholic opposition, was accepted in Europe.

Āryabhaṭṭa I also explained the scientific reasons of the solar and lunar eclipses. His 'Āryabhaṭīya' contains a list of asterisms. The method of calculating their placements and the lunar days for making calendars is also given. The

almanacs based on the 'Āryabhaṭīya' are still followed by the astronomers in south India.

Mathematics has developed in this country as an aid to astronomy and, therefore, Āryabhaṭṭa I had a special chapter on the science of calculations (gaṇita) in his treatise 'Āryabhaṭīya'. Āryabhaṭṭa I was an illustrious mathematician. He gave a turning point to the study of astronomy by applying his new formulae of mathematics for solving astronomical problems. His 'Āryabhaṭīya' consists of four chapters viz., (1) Gītikā Pada (2) Gaṇita Pada (3) Kālakriyā Pada and (4) Gola Pada. The second chapter on mathematics contains 33 new formulae of arithmatic, algebra, geometry and trigonometry. As a philologist, he devised a new method of writing cardinal numbers with the help of different vowels. The chapter on mathematics deals with such topics as square, cubes, square roots and cube roots, area of a triangle and triangular gnomons, a circle, a scalene quadrilateral and of a rhombus. Rules are given to measure the volume of a prism and a sphere and the circumference of a circle. R sine (radius R sine) and the R sine of the zenith distance could be calculated according to Āryabhaṭṭa's rules. He formulated ways to calculate and measure triangles and triangular gnomons, sines cosines and the reversed sines, inverse rule of three and evaluation of unknown values. He described the decimal system of writing numbers and applied the process of arithmatical and geometrical progression for solving astronomical problems. The foundation of algebra was laid by Āryabhaṭṭa I in India. He discovered algebraic solution of quadratic equations and the theory of the pulveriser.

The third chapter of the 'Āryabhaṭīya' enumerates various units of time. The fourth chapter discusses the commencement of equinox, the sun's path, ascending nodes of the planets and the shadow of the earth on the path of the sun. It also discusses the angular difference in relation to the sun at the appearance of moon and other planets.

Following his new discoveries which were amply proved by him, the Hindus acquired sufficient knowledge of the methods of calculation and computation. They had their own system of geometry and of plane and spherical trigonometry which they applied for astronomical calculations. Though trigonometry was not studied as an independent subject, its theories were extensively applied for astronomical calculations around 500 A. D. in India. Āryabhaṭṭa I was aware of the methods of separating the two distinct planetary inequalities, viz., that of the apsis and conjunction in the cases of the 'five-star' planets.

Observational Devices : Gnomons

As the astronomers in those days were mostly occupied with learning and experimenting with the new mathematical principles and theories, the emphasis was, therefore, not so much on the observational astronomy. There were, however, certain Yantras in vogue which were used for celestial observations. The astronomers of this period depended on various types of gnomons, the sundials and the water-clocks etc. Various shapes and sizes of gnomon were used during thefifth century A. D. but Āryabhaṭṭa I prescribed a "broad, massive and large cylindrical gnomon, made of excellent timber, free from any hole, scar or knot on the body". The gnomon was placed in various planes for different astronomical findings.

Armillary Sphere :

One of the earliest descriptions of the Armillary Sphere Instrument is found in the 'Gola Pada' Chapter of the 'Āryabhaṭīya.' Āryabhaṭṭa I described it as a uniformly round circle made of wood or bamboo. It was of uniform weight or density all around and was levelled with mercury, oil or water. A 'Śalākā' (Pin) was fixed in it in the North-South direction. Its description occurs in the 'Bhaṭadīpikā, a commentary written by Paramaḍeśvara on the 'Āryabhaṭīya':

"A sphere of wood, uniformly round on all sides and with uniform density and also light, is made to revolve round an iron axis fixed north-south, without friction (oil may be introduced to avoid friction). To the back side of the sphere is fixed a 'nalikā' (tube) full of water, which has the length equal to the circumference of the sphere and which has a hole at the bottom. Now a thread connected to the hook of the wooden ball (on the top side) passing over another ball the same axis of the wooden ball is attached to the mercury hole by its other end. The mercury lobe is placed on the level of water and water is allowed to flow through the bottom hole and with water, mercury lobe also goes down. The time in which the above hook of ball comes to bottom (180°) is noted. The experiment is repeated with oil. The use of this mechanism is to revolve the ball by water or oil."

Other prominent astronomers of this period were Kalkācārya and Lallācārya. All of them rejected the theory of the diurnal motion of the earth advocated by Āryabhaṭṭa I though his new theories of mathematical calculations for astronomical studies were widely follcwed by the contemporary scholars. Lallācārya (499 A. D.) wrote, 'Śiṣya Dhi Vṛdhi' and 'Ratnakośa' giving the systematic treatment to Indian astronomy. Later astronomers like Bhāskara and others quoted frequently from these books. Lallācārya devised the correct formula for the phase of the moon and improved the theories of planetary motion.

Varāhamihira 500-1000 A. D. :

The period of Varāhamihira could be termed as the golden age of astronomy in India. Varāhamihira was one of the most prominent among the many brilliant scholars of this period. He was born in Kālpi in 505 A. D. Astronomy came to him as a legacy from his father, Āditya Dāsa. Varāhamihira spent a major span of his life at Ujjain, an ancient seat of learning where one of the five observatories of Maharaja Sawai Jai Singh of

Jaipur was set up later in the eighteenth century. In the reign of the famous King Vikramāditya of Ujjain, Varāhamihira became one of the nine 'Ratnas' (jewels) of his Court. This was a period of intense literary activities. Kālidāsa, also of Ujjain, wrote his masterpiece the 'Megha Dūta' during this period. The scholars were extended the state's patronage during this period.

Varāhamihira was well-versed with the three main components of Indian astronomy, viz. Horā (mathematical astronomy), Saṁhitā (universal astronomy) and Jātaka (natal astrology). His learning of these subjects is reflected in his well-known works which include 'Pañca Siddhāntikā', 'Bṛhajjātaka', 'Laghu-Jātaka', 'Bṛhat Saṁhitā', 'Vivāha-Paṭala', 'Yoga Yātrā' and 'Samāsa Saṃhitā'. His 'Pañca Siddhāntikā' (the Five Principles) was the most notable of his books. Known for his erudition, Varāhamihira discussed in his 'Pañca Siddhāntikā' different principles contained in five prominent 'Siddhāntas' (Principles) prevalent at that time. They included the 'Sūrya Siddhānta', 'Pauliśa Siddhānta', 'Romaka Siddhānta', 'Vaśiṣṭha Siddhānta' and 'Paitāmaha Siddhānta'. He endorsed the 'Sūrya' or the 'Saura Siddhānta' as the most authentic of them. Varāhamihira is inseparable from the 'Sūrya Siddhānta' as he is responsible for exploring the principles propounded in this ancient dictionary of astronomy.

The 'Sūrya Siddhānta' is an ancient Hindu treatise on astronomy. Its author and actual period are not known. Some scholars believe that it was compiled by a sage named Sūrya who got this knowledge from devine sources. Others believe that it was written several thousand years ago. There are some references in it to justify this. Some Western scholars, however, consider that it was written between 180 and 100 B. C whereas some other historians are of the view that it was first written around 300 B. C. and alterations and additions in it continued till 1000 A. D. However, it is Varāhamihira who is responsible

for high-lighting and explaining the ancient astronomical theories contained in the 'Sūrya Siddhānta'. Most of his theories, in a way, are based on this treatise as explained herein :

The earth was believed to be a fixed and unsupported sphere around which heavenly bodies revolved. Varāhamihira also stuck to the old belief that the earth was stationary—a fallacy with which he joined his other contemporaries to oppose what was discovered and advocated vehemently by Āryabhaṭṭa I, the doyen of Hindu astronomy. The distances of other planets were calculated on the assumption that they moved with equal velocity. The equation of the centre of a planet was calculated by assuming epicycles. An indigenous notion was introduced by making the epicycles oval.

Varāhamihira described precisely the phenomenon of precession of the equinoxes. The precession was explained as a libration within limits of 27 degrees east or west of a fixed position at the rate of 54 'vikalas' (seconds) per tropical year. The Greek astronomers, Hipparchus and Ptolemy calculated it as 36 'vikalas' (seconds) per tropical year. Modern astronomers calculate the same as 50.2728 seconds. Today it appears astonishing that the ancient Indian astronomers could calculate the minute celestial phenomenon to such a remarkable accuracy. They reckoned the Obliquity of the Ecliptic as 24 degrees. Varāhamihira also revised the existing luni-solar calendar and brought it up to date after taking in account the accumulated precession.

The 'Sūrya Siddhānta' prescribes following units for measuring time :

1	Gurvākṣara	=1.5 seconds
10	Gurvakṣāras	=1 Prāṇa (about 15 seconds)
10	Prāṇas	=1 Vināri (2 min. 24 sec.)
10	Vināris	=1 Nāri (24 minutes)
60	Nāris	=1 Divas (24 hours)

Other units of measuring time are as follows—

1	Prāṇa	= 1 Pala (24 seconds)
60	Palas	= 1 Ghaṭi (24 minutes)
60	Ghaṭis or Ghaṭikās	= Ahorātra (24 hours)

The treatise contains instructions for angular and circular measurements as following—

60	Vikalas (seconds)	= 1 Kala (minute)
60	Kalas (minutes)	= 1 Aṁśa (degree)
30	Aṁśas (degrees)	= 1 Rāśi (Zodiac)
12	Rāśis or 360 Aṁśas (degrees)	= 1 Bhagana (circle)

Another salient feature of the Hindu astronomy of this period was the use of immense cycles. The astronomers had fabricated an epoch of general conjunction to express the planetary elements in integral numbers. They would arrive at it by calculating backward according to the prescribed rules. The determination of the positions of the stars with exactitudes was also practised. The stars, 'Nakṣatras' (asterisms) and 'Yogatārās' (junction stars) along with their astral positions were described by Varāhamihira. The position of the Sun and the moon were determined in relation to the asterisms. The beginning of the Sun's northern and southern courses were considered with its coming on the beginning point of Dhaniṣṭhā (Delphini) and Aśleṣā (Cancri) respectively. Varāhamihira considered 'tithis' (lunar days) as very important. Use of 'tithis' is a unique feature of the Hindu calendar and is still in vogue. This practice was later adopted by Muslims sometime in the eighth century. The 'Sūrya Siddhānta' stated correct formulae for measuring the circumference of a small circle drawn parallel to the equator and passing through a particular place. The Prime Meridian circle was described as passing through Ujjain, thus, making Ujjain in ancient times what Greenwich is in modern astronomy.

The astronomers of this period knew the causes of eclipses and hence they could forecast their exact hour, duration and the extent. They were keen observers and had evolved the methods for finding the longitude and latitude of a particular place on the basis of the beginning and termination of a total lunar eclipse. The longitude of celestial bodies at a given time could be calculated. Likewise they knew how to find out the latitude of the moon and other planets. They calculated the diameter of the moon as 0.33 of that of the earth which is quite close to the correct value of 0.27.

Varāhamihira also discussed in detail the methods of astronomical calculations relating to directions, astral placements and the timings of different planets. The Hindu astronomers had become well-versed in estimating the true positions of the planets accurately. Though not acquainted with the heliocentric motion of planets and Kepler's laws, the ancient Indian astronomers could determine the equation of the centre, the equation of stationary points of planets and the equation of time. This was quite a remarkable achievement of the ancient Hindus. They dealt with the number of rising and setting of stars and planets, their conjunctions and various calculations in a given span of time. Mathematics was widely applied for astronomical calculations in the form of equations indeterminate multiplier, permutation and combination, conversion of quantities and logarithm.

Some Greek influence is evident in the works of Varāhamihira as some Greek terms of astronomy, astrology, cosmology and cosmogony are mentioned by him. Varāhamihira has also quoted the 'Yavanas' (Greeks) while making some of his scientific statements.

ASTRONOMICAL APPARATUS :

Varāhamihira was not merely a theoretician. He tried to prove the principles of astronomy and make further calculations

on the basis of some instruments. His 'Pañca Siddhāntikā' bears descriptions of these 'Yantras'. A brief chapter is devoted exclusively to instruments.

(1) ŚAṄKU :

The Gnomon Instrument was commonly used by Varāhamihira and other astronomers of his period. It had some variations from the earlier form. It was a kind of a rod which was placed into various positions to determine the mid-day and the equinoctial day. They also calculated the latitude of the place, longitude and declination of the Sun and the ascendant of the zodiac signs by placing the gnomon in different planes. The 'Pañca Siddhāntikā' contains instructions for making various types of gnomons. The 'Sūrya Siddhānta' also prescribed rules for making different gnomons and dials for measuring various aspects including the 'agra' (amplitude).

(2) YAṢṬI YANTRA :

Like Śaṅku, the Yaṣṭi (stick), Dhanu (arc) and Cakra (circle) Yantras were also in vogue. Other instruments looking like peacock, monkey and human beings were also used to make observational astronomy more popular. They were used as different types of gnomons for astronomical studies.

(3) KAPĀLA YANTRA :

The Water Instrument in the form of a hemispherical bowl was known as the Kapāla or Kapāli. Some of the instructions to know time are : 'Take a vessel of copper in the form of a half pitcher and make an orifice at its bottom. Leave it in a bigger vessel filled with clean water. When it gets filled up with water, one 'nāḍikā' (24 minutes) would have passed. The orifice at the bottom should be so small as the vessel may sink sixty times in twenty four hours. In practice, undoubtedly, the dimension of the bowl and the orifice were determined by experiment.

(4) UNNATAṀŚA YANTRA :

This Altitude Instrument was a circular instrument whose circumference was divided into 360 equal degrees. Its diameter was of one 'hasta' (about 1.5 feet) and about 1 inch thick. A hole was made at the centre of this circle. It was hung in such a way that it could rotate as and when required. It was kept in front of a planet which was then looked at by keeping the eye on the edge of the circle. A small peg was fixed at the centre, which was used as a medium while observing the planet. The position of the eye on the graduated circle would give the altitude of the heavenly body.

(5) KHAGOLA YANTRA :

It was a Celestial Globe or an Armillary Sphere made of wood. It was utilised to determine different positions of the astral bodies. Varāhamihira could determine declination, hemisphere, altitude, azimuth, meridian pass time, zenith distance, longitude and zodiac ascendants. Astronomers of the period used this instrument to demonstrate and explain various theoretical aspects of astronomy to their disciples.

The Gola Yantra or the Armillary Sphere has been described as follows in the 'Sūrya Siddhānta' : "Let the astronomer frame the surprising structure of the terrestrial and celestial spheres. Having caused a wooden globe to be made (of such size as he pleases), to represent the Earth, with a staff for the axis passing through the centre and exceeding the globe at both ends, let him place the supporting hooks. as also the equinoctial circle.

'Three circles must be prepared (divided for signs and degrees), the radius of which must agree with the respective diurnal circles, in proportion to the equinoctial. The three circles should be placed for the Ram (Meṣa) and following signs respectively, at the proper declination in degrees N. or S., the same

answer contrariwise for the Crab (Karka) and other signs. Likewise, three circles are placed in the southern hemisphere for the Balance (Tulā) and the rest, and contrariwise for Capricorn (Mṛga) and remaining signs. Circles are similarly placed on both hoops for the asterisms in both hemispheres as also for 'Abhijit' and for the 'Sapta Ṛṣis', 'Agastya', 'Brahmahṛdaya' and other stars. In the middle of all these circles is placed the equinoctial. At the intersection of that and supporting hoops, the distance from each other half the sign, the two equinoxes should be determined and the two solstices at the degrees of the obliquity from the equinoctial and the places of the Ram (Meṣa) and the rest, in the order of the signs, should be adjusted by the strings of the curve. Another circle, thus, passing from equinox to equinox, is named the ecliptic and by this path, the Sun illuminating worlds, for ever travels. The moon and other planets are seen deviating from their nodes in the ecliptic to the extent of their respective greatest latitudes (within the zodiac)."

Further instructions suggest that this Yantra may be made to revolve with regularity by a current of water. Appearance of spontaneous motion may be given by a hidden mechanism for which quick silver could be utilised. There seems to be a hint of secrecy about its mechanism and hence it was advised that the construction and the working of its mechanism should be learnt from an experienced teacher. More details about this mechanism are, however, not available.

Alberuni, the famous Persian scholar in his book entitled 'Bhāratavarṣa' has praised Varāhamihira, his instruments and methods of observational astronomy. Astronomers had started taking more interest in the observational astronomy and they made and utilised various instruments for this purpose.

After Varāhamihira came Śrīsena, Kalyāna Varmā and Viṣṇu Candra on the scene of astronomy in the sixth century. They followed the principles of their predecessors and wrote

commentaries on them. Kalyāna Varmā's famous book on astrology 'Sarāvalī' is consulted by the Indian astrologers even today.

Brahmagupta :

This erudite scholar of astronomy and mathematics was born at Bheenmal in western Rajasthan in 598 A. D. After his studies, he migrated to Central India and served as the court astronomer to the King of Rewah, known as Vyāgrahabhaṭa. Later he settled at Ujjain, an ancient seat of learning in Madhya Pradesh (Central India). Brahmagupta rose like a luminary and shined brightly on the horizon of Hindu astronomy in the seventh century.

He made his debut in the field of astronomy and mathematics by writing the 'Brahmasphuṭa Siddhānta' which became one of the most celebrated treatises on Hindu astronomy. His other Chef d'oeuvre is known as the 'Khaṇḍa Khādyaka' which literally means the 'food prepared from sugar candy'. He wrote this book in protest against a Buddhist work, the 'Lavaṇa Muṣṭi' (the handful of s lt) which severely criticised astronomy. Brahmagupta contradicted the Buddhist criticism of astronomy and upheld it as a subject of the intellectuals and scholars. Both of these masterpieces of Brahmagupta held sway for centuries together in ancient India.

Brahmagupta was a brilliant mathematician. Bhāskara I, a contemporary of Brahmagupta, acknowledged his authority on algebra and placed him at the zenith in the galaxy of Indian astro-scholars. Bhāskarācārya II, a prominent astro-scholar of the twelfth century praised him in his 'Bīja Gaṇita' as 'Gaṇaka-Cakra Cūḍāmaṇi' which literally means the greatest among the great mathematicians. Bhāskarācārya II also based his treatise 'Siddhānta Śiromaṇi' on the principles propounded by Brahmagupta.

Brahmapupta ushered in a new era of mathematical research. Though the foundation of algebra was first laid by his predecessor Āryabhaṭṭa I, Brahmagupta also made exemplary advances by contributing a great deal to this subject. He contradicted some of the principles and methods of his predecessors like Āryabhaṭṭa I and propounded many new methods of calculations and constants of greater accuracy. His treatment of parallax in the calculation of solar eclipses as given in his 'Khaṇḍa Khādyaka' is also different from that of his predecessor Āryabhaṭṭa and others.

Brahmagupta is responsible for introducing various new methods of calculations to solve a number of astronomical problems. He was the first Hindu astro-mathematician to use the 'second difference' in the calculations of inequalities. He gave a turning point to the study of astronomy in India by dealing with the solution of diurnal problems involving spherical trigonometry. His work in the trigonometrical ratios was very significant. The credit for solving numerous astronomical problems with the help of algebraic equations also goes to Brahmagupta. He introduced the method for solving indeterminate equations known as 'Kuṭṭaka' or 'pulveriser'. The pulveriser was largely used for solving astronomical problems involving the sun, the moon and the planets with their nodes, apogees etc. His contribution to geometry was very significant as he devised new formulae for the measurement of triangles, squares etc. His most important work, however, was on quadrilaterals and solids.

Brahmagupta was an independent thinker of 'Grahabhāgana' or the planetary motions. He calculated and stated the number of rotations of each planet around the Zodiac circle during 43,20,000,000 years. He was also an expert of 'Tripraśnādhikāra' three problems of directions, astral position and time with respect to celestial object. He discovered various principles to determine

the true position of the planets and the theories of accentric cycles and epicycles for the equation of the centre of the planets.

Brahmagupta was a great critic who waged an intellectual war on three fronts. Firstly, he contradicted the Buddhist criticism of Hindu astronomy. He also contradicted some of the theories and methods adopted by his predecessors like Āryabhaṭṭa I, Varāhamihira, Śrīsena and Viṣṇucandra as he believed that they could not calculate correctly. He discarded some of their tables and findings. He held, "the old calculations dealing with the planets, i. e. the old astronomy based on the system of Brahma, have become erroneous in course of past ages and, therefore, I, the son of Viṣṇugupta, would like to clarify them." He further stated in his 'Brahmasphuṭa Siddhānta' that the determination of the planetary positions should agree with the actual observation of the planets.

Secondly, Brahmagupta retarded the Greek influence on Hindu astronomy as witnessed before he came on the scene. He criticised Greek methods of calculations and refuted their claim for a greater accuracy by introducing various novel methods of astronomical studies and calculations. Thirdly, Brahmagupta placed Hindu astronomy on the spring board from where it took off and reached the Arabs. His epoch-making works, the "Brahmasphuṭa Siddhānta" and the 'Khaṇḍa Khādyaka' were the first books on Indian astronomy to have been translated in Arabic by the names of 'Al Sindhind' and 'Al Arkand' respectively. Hence the knowledge of Hindu astronomy reached Arabs in the seventh-eighth centuries and later it migrated to Europe. Scholars like Alberuni of Persia were of the view that the Arabs learnt astronomy from Brahmagupta's works before being acquainted with those of Ptolemy.

According to Encyclopaedia Britannica, the principles of 'Bīja Gaṇita' (algebra) of Brahagupta propounded in about 628

A. D. are regarded as the first authentic and systematic work on algebra. Later Mohammad Ibn Musa al Khowarizmi wrote in Baghdad in C. 825 A. D. a book entitled 'Algebra W' al muqubalah (Restoration and Equation). This was the first work with the title of Al-gebra which means equation in Arabic. This work was undoubtedly based on the principles of 'Bīja-Gaṇita' of Brahmagupta.

'JYOTIṢA YANTRAS' FOR ASTRAL OBSERVATIONS :

Brahmagupta was not a mere theoretician. He was a 'Dṛg-gaṇitagya' who believed that the results arrived at by mathematical calculations should agree with those by actual observations. He based his conclusions on direct observations of the celestial phenomenon. He was an expert observer and well-versed in making and employing various 'Jyotiṣa Yantras' for making corrections in the existing theories. His foot-prints were later followed by Maharaja Sawai Jai Singh of Jaipur in the eighteenth century. Brahmagupta observed that on the equinoctial day, the sun rises at the exact east point on the horizon making the entry of the Sun in tropical sign of Aries.

This devoted observer of the visible heavens ushered in a new era of observational astronomy in India in the seventh century. He improved and applied some of the earlier instruments like the Armillary Sphere of Varāhamihira, hitherto used for demonstration purpose, for actual observations. He described the method of making and applying astronomical instruments in 'Yantrādhyāya'—a chapter on instruments in his 'Brahmasphuṭa Siddhānta'. The instruments referred to by Brahmagupta are :

(1) DHANUR YANTRA (The Bow Instrument) :

It was a kind of altitude and time instrument to determine 'naṭa' (inclination) and 'unnatakalā (altitude) ghaṭikas'. It was made in the form of a bow.

(2) CAKRA YANTRA (The Wheel Instruments) :

The circumference of this Circular instrument was graduated in degrees indicating twelve Zodiac signs. It was made of wood.

(3) YAṢṬI YANTRA (The Pole or Staff Instruments) :

It was used to record time at different parts of the day. 'Dṛgya' and other characteristics could be calculated by its shadow. It was used for ascertaining the solar lunar differences and for fixing up the directions. It was also used for determining various heights and altitudes.

(4) KARTTARĪ YANTRA (The Scissor or Cutter-Instrument) :

It was made in the shape of a pair of scissors with two semi-circular blades fastened to a string at the centre where a pin or a pole casting shadows was fixed. More details of this Yantra are not available.

(5) PĪṬHA YANTRA :

Details of this Yantra are not available though it is termed as the Pedastral or Seat Instrument.

(6) GHAṬIKĀ OR KAPĀLA YANTRA (The Water Clock) :

It was a kind of a clock or the Pot instrument which was made in the shape of a hemispherical bowl with a hole at its bottom. The Yantra was filled with water which would flow out by the hole provided at the bottom indicating 'ghaṭikās', a unit of time equivalent to 24 minutes.

(7) TURYAGOLAKA YANA (The Quadrant Instrument) :

The Quadrant Instrument was one of the most important instruments devised by Brahmagupta. It consisted of an arc of 90 degrees. Sines of degrees were graduated on it. Attached to it was a movable vertical gnomon which could be utilised for determining the altitude, sine of latitude, declination, longitude ascensional difference etc.

(8) KHAGOLA YANTRA (The Armillary Sphere) :

Brahmagupta made extensive use of the Armillary Sphere Instrument. This Yantra had been described and employed by his predecessors Āryabhaṭṭa I and Varāhamihira who utilised it mainly for demonstration purpose. Brahmagupta employed it for actual observations for his astronomical studies.

(9) SALILA YANTRA : (The Water Leveller Instrument) :

To ascertain whether a surface was well levelled or not, the Water Leveller was used as a liquid seeks its own level. The levelled surface was later used for making dials and fixing gnomons.

(10) BRAHMA OR SĀNA YANTRA :

It was a small device used for describing various circles.

(11) AVALAMBA SŪTRA YANTRA (Threads with Plumbs or Plumb Lines) :

This simple Thread Instrument was used for adjusting vertical lines.

(12) KARṆA OR CHĀYĀKARṆA YANTRA :

It was a set of square for diagonals used in connection with angles and diagonals for making various instrumets and charts.

(13) CHĀYĀ OR SAṄKU CHĀYĀ (The Sun-Dial) :

It was a kind of a Sun dial in which the 'Chāyā' (shadow of the gnomon) was taken into consideration for various astronomical readings.

(14) DINĀRDHA YANTRA (The Meridinal Instrument) :

This was a 'mid-day measure' instrument meant and used for various celestial observations at mid-day.

(15) ARKA YANTRA :

It was termed as the Sun Instrument though details are not available about it.

(16) AKṢA OR PALANŚA YANTRA :

It was in the form of a small arc instrument for measuring degrees.

(17) ŚAṄKU YANTRA (The Gnomon Instrument) :

The Salila, Śana, Avalamba Sūtra, Karṇa, Śaṅku Chāyā, Dinārdha, Arka and Akṣa (Palanśa Yantra) were mainly used for adjusting and ascertaining various astronomical planes.

It consisted of a gnomon which was placed in different planes for various astronomical observations by Brahmagupta. The Gnomon was an important instrument and utmost care was taken to fix it. The level of the surface to install the gnomon was ascertained with the help of the Salila Yantra. Then a circle of any radius was drawn and a vertical gnomon was fixed at its centre. Though various types and dimensions of the gnomon were in vogue in the seventh century, a large, cylindrical and massive gnomon was always preferred. With the help of the Avalamba Sūtra (four threads with plumbs) it was ascertained whether the gnomon was perpendicular. Brahmagupta in his 'Brahmasphuṭa Siddhānta' favoured a gnomon which was two 'aṅgulas' (finger-width) wide at the bottom and pointed like a needle, twelve 'aṅgulas' in length and full of holes from the basic circular part to the pointed extremity. The gnomon was also used for finding directions by Brahmagupta. He mentioned the rules for it in his 'Brahmasphuṭa Siddhānta' as "the level of the gnomon is ascertained by means of water and a gnomon of twelve 'aṅgulas' is set up. Two points where the shadow of the gnomon enters into and passes out of the circle are found out." Brahmagupta mentioned further that if the sun is on the eastern side then where the shadow point enters the circle (in the forenoon), would be the west and the point where it emerges out (in the afternoon) is the east.

The declination of the sun changes as it moves along the ecliptic and, therefore, the sun traverses some distance of the

ecliptic by the time the shadow moves between the forenoon and afternoon points as mentioned above. Hence, the East-West line determined by the above method is not true. According to Shukla, Brahmagupta (628 A. D.) was the first Hindu astronomer who prescribed the determination of the East-West line with proper allowance for the change in the sun's declination.

Brahmagupta made numerous use of the gnomon. He prescribed rules for finding the latitude, colatitude, the zenith distance and altitude of the sun by measuring the length of the shadow and the length of the gnomon. He surpassed his predecessors when he devised rules for determining the latitude with the help of the sun's meridian, Zenith distance and declination.

BHĀSKARA I:

The traditions of astronomical observations and mathematical calculations set up by Brahmagupta were carried on by his successor astronomers. Bhāskara I was one of the most brilliant scholars among Brahmagupta's contemporaries. His well known works on astronomy include (1) 'Mahā Bhāskarīya' (2) a Commentary on the 'Āryabhaṭīya' of Āryabhaṭṭa I and (3) 'Lahu Bhāskarīya'. Though Brahmagupta criticised some of the theories of Āryabhaṭṭa I, Bhāskara I was a staunch follower of him (Āryabhaṭṭa I) and explained in detail the 'Āryabhaṭīya' in his commentary which throws ample light on the development of astronomy during the sixth and seventh centuries in India. Āryabhaṭṭa I, Varāhamihira, Brahmagupta and Bhāskara I constitute a most significant time-sequence in the history of Indian astronomy.

Bhāskara I followed the traditions of observational astronomy set-up first by Āryabhaṭṭa I and later strenghened by Brahmagupta. In his commentary on the 'Āryabhaṭīya', he mentions that testing of the level of the ground for setting up gnomons was crucial. "When there is no wind, place a jar (full) of water upon a tripod on the ground which has been

made plain by means of eye or thread and bore a (fine) hole (at the bottom of the jar) so that the water may have continuous flow. Where the water falling on the ground spreads in a circle, there the ground is in perfect level, where water accumulates after departing from the circle of water it is low and where the water does not reach, there it is high."

Once the ground was levelled, a prominent and neat circle was drawn on the surface. Sandal paste was widely used for drawing astronomical lines on the ground. Then another small concentric circle was drawn with the radius of the gnomon. A vertical gnomon was then set up at the centre of the bigger circle. The astronomers were very particular about the vertical plane of the gnomon, which they verified with the help of four plumb lines hung on all the four sides of the gnomon.

In the commentary on the 'Āryabhaṭīya', Bhāskara I mentioned that various types of gnomons were in vogue in the sixth and seventh centuries and that the astronomers differed regarding the shape and size of the gnomon. One of the gnomons in use was the one with its one-third in the bottom of the shape of a prism placed on a square base, one third in the middle of the shape of a cow's tail and the remaining one third at the top in the shape of a spearhead. Some astronomers however, favoured a square prismoidal gnomon. Bhāskara I preferred the gnomon prescribed by Āryabhaṭṭa I – a massive and large cylindrical gnomon made of excellent timber and free from any hole, scar or knot on the body. For getting the shadows easily and distinctly, a fine iron or wooden nail was fixed vertically at the centre of the upper end of the cylindrical gnomon. The nail was to be longer than the radius of the gnomon so that its shadow was always clearly visible on the ground.

Though various types of gnomons were prevalent in ancient India, there were no hard and fast rules. According to Bhāskara I,

the gnomon could be of any length and any number of divisions. In general, a broad and massive gnomon was preferred by the astronomers of this period as its vertical plane was unaffected by the wind.

Bhāskara I further described the method of determining directions. A vertical gnomon was fixed at the centre of a circle drawn on the levelled surface. Two points were marked where the shadow of the gnomon entered into and passed out of the circle. He prescribed drawing out a fish figure with these points. The thread line which went through the mouth and tail of the fish figure, indicated the North and South directions with respect to the gnomon. Thus, a number of gnomons were in vogue during the seventh century in India and they were used for different observations of time, astral positions and directions.

Muñjal, Bhaṭṭotpal, Śrīpati and Maheśvara were other prominent scholars among Brahmagupta's contemporaries. Bhaṭṭotpal was a famous critic and commentator of Varāhamihira's works. His works include 'Gaṇita Skandha' and 'Praśnajñāna'. Muñjal was also a scholar of repute who wrote 'Laghu Manasa' and 'Bṛhat Manasa' in 932 A.D. These books served as the basis of research for the astronomers who succeeded Muñjal. Muñjal gave the 'ayanāṁśa' (a correction for the accumulated precession) as 6 degrees 50 minutes since Varāhamihira corrected the calendar in about 500 A. D. Another correction referred to by Muñjal in his works is for the moon's motion known as 'evection'.

Āryabhaṭṭa II (b. 953 A.D.) was another prominent scholar of this period (500-1000 A.D.). His treatise the 'Mahā Āryabhaṭīya' was quite significant from astronomical point of view. Śrīpatī also contributed to the advancement of astronomy by writing a brilliant book entitled 'Siddhānta Śekhara' in 1039 A. D. It included three corrections, viz., the correction for the equation of time owing to obliquity and correction to rectify

the east-west line based on gnomonic shadows. His 'Siddhānta Śekhara' is widely consulted by Indian astronomers even today. His other important works include 'Jātaka Paddhati', 'Śrīpati' Paddhati, 'Ratnasāra', 'Ratnamal' and 'Ratnāvalī'. Maheśvara, the father and guru of celebrated Bhāskarācārya II, was a brilliant scholar himself whose 'Karaṇa-grantha Śekhara' on mathematical calculations for astronomical studies and 'Pratiṣṭhā Vidhi Dīpaka' are well known works of his times.

ASTRONOMY IN MEDIAEVAL INDIA

Bhāskarācārya II :

Bhāskara II was an illustrious astronomer who is compared with Varāhamihira and Brahmagupta. His contribution in the field of astronomy and pure mathematics made him the greatest astro-mathematician of mediaeval India. He was born in Vijjad-vid in 1114 A. D. His father was also a scholar of astronomy and, thus, like Varāhamihira he got the aptitude and talent for astronomy in legacy. Like his predecessor Brahmagupta, Bhāskarācārya II realised and stressed the importance of corrections in the prevailing theories of astronomical calculations and tables with the help of instruments. Though a pure mathematician of repute, Bhāskara II was also a practical astronomer and an expert observer.

Bhāskarācārya was a man of letters. His four famous works are the 'Siddhānta Śiromaṇi' (two volumes), 'Karaṇa Kutūhala', 'Bīja Gaṇita' and 'Līlāvatī'. Moghul Emperor Akbar was so much impressed by the knowledge contained in 'Līlāvatī', the work named after Bhāskara's daughter, that he got its Persian version translated by his court astronomers in the sixteenth century.

Bhāskarācārya II was responsible for highlighting the gravitational power of the earth. He propounded the thesis that the earth has a tendancy to attract other objects towards

itself due to its own force of gravitation. The concept sounded somewhat unusual to his contemporaries. However, some five centuries later, it was reiterated by Sir Issac Newton in England. Bhāskara also clarified that the earth was surrounded by a number of orbits of different planets. He believed that the earth had no base of its own. It held its position due to its own magnetic force. He, consequently, applied the same theory to other planets.

Bhāskarācārya was a devoted researcher of astronomy, It was he who discovered the principle of 'Udayāntara-Saṁskāra' which means the difference between the mean time and the true time of the Sun rise. This difference of the rising times applies to the stars and planets also. His other discoveries included a correct formula for the equation of time. Bhāskarācārya's formulae of 'corrections' came long before those of Flamsteed of England, advocated in 1700 A. D. Besides 'Udayāntara, the other three corrections discovered by him included 'Deśāntara', 'Carāntara' and 'Bhujāntara'. He explained the 'Deśāntara' as a correction due to the difference of longitude between the zero meridian and the meridian of the place concerned. 'Carāntara' was explained as a correction due to the difference of latitudes and 'Bhujāntara' as the correction due to the positions of the planets at the mean mid-night and the true mid-night. It was related to the correction due to the equation of the centre. The 'Udayāntara' as already mentioned is a correction due to the equation of time because of the obliquity of the ecliptic.

The Hindu astronomers observed the celestial sphere more minutely than before during this period. They became aware that the point above which the planets revolved did not coincide with the earth's centre as Bhāskara himself said : "The centre of the earth is the centre of the celestial sphere but the centre of the circle in which the planet moves does not coincide with the earth's centre."

Other theories advocated by Bhāskara included the epicyclic theory and the method of eccentric circles for obtaining the geocentric positions of the planets. Computation of 'tithis', computation of 'nakṣatra', daily variation in the equation of centre, retrograde motions etc. were some other topics elaborately dealt with by Bhāskarācārya II.

Another characteristic feature of this period was the creation of a number of astronomical instruments. The system of actual observation started by Brahmagupta was carried on by Bhāskarācārya for studying the practical aspects of astronomy. Bhāskarācārya prescribed the methods of making and employing various astronomical apparatus for determining the placements and movements of the astral bodies in the heavens.

ASTRONOMICAL APPLIANCES :

Bhāskarācārya was a keen star gazer. In his 'Siddhānta Siromaṇi', he stated that without the help of the instruments it was impossible to determine the minute aspects of time. He described various 'Yantras' for the purpose of the minute study of the firmament as follows :

(1) GOLA YANTRA : (The Celestial Globe) :

The Globe was made either of wood or metal. A number of threads or wires were fixed criss-crossing each other representing different astronomical lines like meridian circle, celestial equator, horizon, vertical circle, movable zodiac circles etc. Various points indicating prominent stars and planets were also studded on this mini-celestial sphere. This celestial globe was used for demonstrating the theoretical and practical aspects of astronomy.

(2) NARIVALYA : (The Celestial Equator) :

Bhāskarācārya prescribed rules for making the celestial equator that a circle of wood be made wiht

its circumference graduated into 'ghaṭis' and its sub-divisions. A gnomon, vertical from the surface of this dial should be fixed to complete this Yantra. The shadow of the gnomon was observed to know time. It also indicated the hemispherical positions of the celestial bodies when the Yantra was placed in the plane of equator. The Yantra was placed in the plane of horizon to determine the azimuth with the help of graduations of 360 equal degrees on the dial.

(3) YAṢṬI : (The Gnomon) :

'Yaṣṭi' literally means a rod or a pole. No detailed descriptions are given about this simple Yantra in the 'Siddhānta-Śiromaṇi' though it is stated that the gnomon should be made of ivory and that it could be utilised to determine time, altitude, azimuth etc.

(4) GHAṬĪ YANTRA : (The Sand or Water-Clock) :

This Yantra was an improved version of the earlier Sand or Water-Clock for measuring time. The Yantra was made of copper in the shape of a 'ghaṭī' or a half pitcher which had an orifice at the bottom. It was left in a bigger water vessel and time was observed by its sinking. Sand was also used in a similar vessel and time was determined by observing it.

(5) CAKAR YANTAR : (The Circle Instrument) :

This Circular Instrument was made of wood or metal and its circumference was graduated in 360 degrees. It was suspended with the help of a loose chain ond a rod was fixed at its centre. It was utilised to determine the altitude and declination of the Sun by placing it in various positions.

(6) CĀPA YANTRA (The Arc Instrument) :

Half a circle was employed to make the Arc Instrument. It was used to determine the altitude, meridian pass time, zenith distance and time. A gnomon was placed at the centre of the arc and its shadow was taken into account.

(7) TURĪYA YANTRA (The Quadrant Instrument) :

The Quadrant Instrument was first devised by Brahmagupta in the seventh century and later employed extensively by Bhāskarācārya and his contemporaries. The Yantra consisted of a 90 degree quadrant and was employed to observe altitude, time, declination, longitude and latitude of planets.

(8) PHALAKA OR DHĪ YANTRA :

Bhāskarācārya claimed to have invented this yantra which according to him was an "excellent instrument calculated to remove always the darkness of ignorance and is the delight of clever astronomers."

This astronomical device consisted of a board divided by horizontals into 90 equal parts. Other various celestial lines were also depicted for astronomical calculations. It was suspended by a chain for making observations. It was, in fact, a simple astrolabe which was devised by Bhāskarācārya II. It was based on the Cakra Yantra and was developed like a celestial map.

Bhāskarācārya pinned his faith more on astronomical devices than on theoretical calculations for celestial studies. He was more a practical astronomer like Brahamagupta, who would always verify the existing theories with the help of instruments. He went to the extent of saying that a clever astronomer could measure the positions of all objects visible in the sky, water or on the earth by taking a long wooden stick in hand and observ-

ing the heavenly bodies on its outer end by keeping the eye on the inner end. He termed it as the Dhī Yantra which referred to the angular calculations by expert astronomers. Bhāskarācārya also referred to a self moving instrument with the help of mercury though there is no evidence that this device really worked.

Other prominent scholars of this period were Keśava, Rājāditya, Padmaprabha Sūri and Naracandra Upādhyāya. Keśava's 'Vivāha Vṛndābana' is a good 'Muhūrta Grantha' which lays down rules for determining the auspicious hours for marriages and other Hindu rites and ceremonies. Rājāditya was an eminent scholar of the south who was the first to write treatises in Kannada language. His books on mathematics and astronomy include 'Vyavahāra Gaṇita', 'Kṣetra Gaṇita', 'Aṅka Gaṇita', 'Bīja Gaṇita', 'Rekhā Gaṇita', 'Citra Suge' and 'Vyavahāra Ratna'. Padmaprabha Sūri wrote 'Bhuvana Dīpaka', 'Phalita Graha', 'Bhava Prakāśa' etc. Naracandra was a famous Jain scholar of this period who wrote 'Bera Jātaka' whose commentaries are still read by astrologers in India.

Mahendra Sūri :

Mahendra Sūri belonged to Bhrigupur and was a disciple of Madana Sūri. Astronomer-scholars continued getting the patronage from the monarchs during the mediaeval period. Mahendra Sūri was the Chief Court astronomer of Feroz Shah Tughlak. His 'Yantra Rāja', written in 1370 A. D., soon became a well known work on observational astronomy. The work contains five chapters on mathematics and instruments, viz.' Gaṇita Adhyāya, Yantra Ghaṭanādhyāya, Racanā Adhyāya, Yantra Śodhana Adhyāya and Yantra Vicāra Adhyāya.

INSTRUMENTS :

YANTRA RĀJA : (The Astrolabe) :

Mahendra Sūri referred to a number of astronomical instruments employed by his predecessors like Brahmagupta and

Bhāskarācārya. His most favourite instrument was, however, the 'Yantra Rāja' or the astrolable. Though he knew about the astrolabes of the Muslims but in his astrolabe, he also incorporated the ideas of his predecessor Hindu astronomers about the celestial sphere and its observation.

Keśava II, Gaṇeśa Daivagya, Ḍhuṇḍhirāja, Nīlakaṇṭha and Nṛsiṃha are some other scholars who rose on the scene of astronomy in the fifteenth and sixteenth century. Keśava II wrote 'Siddhānta Vāsanā', 'Graha Kautuka' and 'Kundāṣṭaka' on astronomical calculation. Gaṇeśa Daivagya wrote famous 'Graha Lāghava', Bṛhattithi Cintāmaṇi' etc. He also wrote commentaries on three works of Bhāskarācārya viz. 'Siddhānta Śiromaṇi,' 'Līlāvatī' and 'Vivāha Vṛndābana.' 'Jātaka Bharaṇa,' a work on astrology of Ḍhuṇḍhirāja, is still consulted by Indian astrologers. Nīlakaṇṭha's 'Tājik Nīlakaṇṭhī' (in Sanskrit) which is based on the Greek and Arab-astrology, is studied as a text book, by the students of astrology. Nṛsiṃha wrote 'Graha-Kaumudī'.

1500–1750 A. D. :

Rāma Daivagya was also a famous scholar during the reign of Emperor Akbar. He wrote 'Rāma Vinoda' (tables) and 'Muhūrta Cintāmaṇi'. To please Raja Todarmal, a Minister of Emperor Akbar, he wrote another book entitled 'Toḍarānanda' on astronomy and astrology. He was also known as Rāma Bhaṭṭa. Raṅganātha was another astro-scholar of the sixteenth century who wrote detailed commentaries of the 'Sūrya Siddhānta' which are still consulted in India. Kamalakar Bhatta was well known writer of 'Siddhānta Tattva Viveka' which is widely read in the country. The 'Megha Mahodaya' of Megha Vijayagaṇi was a well known work on universal astrology in the seventeenth century. His other works on palmistry came to be known as the 'Hasta Sañjīvanī' and 'Ramala Śāstra' the latter being based on the Greek knowledge of astrology of dices. It contains various astrological interpretations based on the calculations of dices.

During this period astronomy remained merely as a subject for the few intelligent people and no fresh thought was added to its age-old realm mainly because it was a period of social and political upheavels throughout the country. Values had undergone a vital change following a rudimentary turn given to society by the new Moghul rulers. The astronomers counted upon the old works and nearly stopped the astronomical observations and research for the advancement of astronomy. Hindu religion, culture, literature, and astronomy suffered a set back during the repeated Muslim invasions. The fanatic faction even went to the extent of wrecklessly burning the libraries and destroying the irreplaceable treasures of learning in the country. The advancement of this science suffered a severe jolt as astronomers did not receive the state patronage and protection. It was a period when sea of faith in astronomy was receding. However, astrology, a more practical science, came to stay as a popular device, replacing astronomy. Emperor Akbar (1556-1605 A. D.) was a staunch believer of astrology and consulted his court-astrologers everyday. He constructed the Astrologer's Seat in his Royal Castle at Fatehpur Sikri where his personal astrologer would sit, calculate astrologically and advice the Emperor regarding the colours of his garments and jewels and some other do's and don'ts for the day. Similar astrological practices were followed by people throughout the country during this period.

MAHARAJA SAWAI JAI SINGH : (Plates Nos. 1A, 1B, 1C)

In this transition period emerged Sawai Jai Singh, the ruler of Amber and Jaipur (1699-1743 A. D.) to restore the faith in astronomy. He stood firm like a rock and provided beacon light to illuminate the gloomy quarters by introducing observational astronomy with a difference in India. A contemporary of five Moghul Emperors, Sawai Jai Singh was a keen astronomer-ruler who propagated this ancient science throughout

the country. The five stone observatories he built stand as the living testimony of his devotional urge for this science.

Sawai Jai Singh's cotribution to astronomical studies is very significant. He revived the old traditions and ushered in a new era of celestial observations in India. He is regarded as one of the most prominent Hindu astronomers for his unique contribution to the advancement of this science during the 'dark-age' of Indian history. Besides raising his massive stone observatories in the country, he wrote the 'Yantra Rāja' in two volumes to explain the theory and practice of the astrolabe. He got a number of books on astronomy and mathematics translated from Arabic and Persian into Sanskrit by scholar astronomers to know what was happening in this field elsewhere in the world. He patronised scholars like Pandit Jagannath 'Samrat', Pandit Kewal Ram, Pandit Ratnakar Pundarik and Pandit Vidyadhar in his court.

It is Sawai Jai Singh who blew a trail of fresh learning for astronomy. He will be remembered for ever for setting a unique tradition at a time the lure for ancient cult was slowly dying out in the wake of a new civilization taking shape following intermingling of several cultures into the mainstream of Hindu philosophy.

It is, thus, evident that the Hindu school of astronomy which originated during the Vedic times and evolved through the ancient and medieval times maintained its originality. The Hindus were creative thinkers and they contributed a great deal to the advancement of astronomy and mathematics in the world.

INTELLECTUAL INFLUENCES :

Babylon, China, Greece, Egypt and Latin America were other ancient cradles of civilization where astronomy flourished and swung high. The ancient Chinese and Babylonians had

significant knowledge of astronomy. The Chinese had developed an advanced type of Sun-Dial and a calendar of 365 days around 2500 B. C. The ancient Chinese predicted eclipses. They knew about five planets and called them 'wandering-stars'. The Babylonians made observations and calculations of stars and planets whom they worshipped as gods. It was a form of nature worship. They also evolved some mathematical calculations and used the sexagesimal number system. The Egyptian Civilisation developed on the banks of the Nile and hence the floods were predicted according to the rising of certain stars like Sirius. They had also developed a calendar of their own based on the steller positions. They built their great Pyramids in line with the prominent stars like the Pole Star.

The Greeks learnt from the Babylonians how to determine the positions of the stars and planets, predict eclipses and divide the asterisms. Their astronomy began to develop as a science around 700 B. C. Astronomer Thales of Miletus (b. 640 B. C.) believed the universe to be spherical. Notable Greek philosopher-astronomer Aristotle (384-322 B. C.) maintained that the earth was round on the basis of his observation of certain stars and the earth's curved shadow on the moon during an eclipse. Hipparchus (190-120 B. C.) is termed as the greatest Greek astronomer who invented some principles of trigonometry, prepared a star catalogue and discovered the precession of the earth's axis. The theories advanced by Hipparchus were later followed by another prominent Greek astronomer Ptolemy (90-170 A. D.) in his masterpiece the 'Mathematike Syntaxis', better known as the 'Almagest'. Ptolemy considered the earth as the centre of the universe for calculating the astral placements. The planets and the sun were believed to be revolving around it. He introduced the theory of epicycles and deferents regarding the planetary movements. No advances were, however, made by the Greeks after Ptolemy as the Greek civilization was on the decline.

Some scholars argue that the knowledge of astronomy in India came from Babylonia. There were mutual contacts and exchange of ideas between these two ancient cultures but the basic difference in their astronomical conceptions suggest that the Hindus were original thinkers and they evolved their own principles of astronomy. The Babylonians divided the asterisms by keeping the motion of the sun in view whereas the ancient Indians divided the sky into twenty-eight asterisms in relation to the motion of the moon.

Famous German scholar Max Müller observes in his 'Objections': "We must never forget that what is natural in one place is natural in other place also and... no case has been made out in favour of a foreign origin of the elementary astronomical notions of the Hindus as found or pre-supposed in the Vedic hymns'. He further writes, 'the twenty seven constellations which were chosen in India as a kind of lunar zodiac were supposed to have come from Babylon. Now, the Babylonian Zodiac was solar and inspite of repeated researches, no trace of lunar zodiac has been found... But supposing even that a lunar zodiac had been discovered in Babylon, no one acquainted with the ancient Vedic ceremonials would easily allow himself to be persuaded that he Hindus borrowed that simple division of the sky from the Bobylonians. It is well known that most of the Vedic sacrifices depend on the moon, far more than on the sun."

There had been some exchange of astronomical theories between Greece and India though the two schools maintained their own distinct characteristics. A number of terms connected with astronomy, astrology and mathematics were translated from Sanskrit works to Greek and vice-versa. The astronomical works of Varāhamihira written in the sixth century contain some Greek terms of astronomy : nd their notions of cosmology and cosmogony. Varāhamihira quoted the 'Yavanas' (the people from the West) in some of his scientific pronouncements. The Greek

references in Varāhamihira's works are of the period of Hipparchus (2nd century B. C.) who preceded Ptolemy.

The division of the orbit of the sun into 27 or 28 parts for the study of the motion of the moon is entirely of Hindu origin. The division of the ecliptic into twelve parts, viz., the zodiac signs is also a distinct feature of Hindu astronomy though their names might have been adopted later. 'Ahorātra' (day and night) being divided into 60 'ghaṭikās' is another original Hindu practice for calculating time, though the seven day—week is believed to be adopted from the Greeks. In the field of mathematics, the cardinal numbers from one to nine and zero and the decimal system are undoubtedly of Hindu origin. The Hindus used sines, reversed sines and cosines whereas the Greeks applied chords in their calculations. The Indian system of numbers along with the astronomical tables reached Arabian countries with an Indian ambassador in 773 A. D. This system reached Europe from Arabia the 12th century and came to be known as 'Algoritmus'.

According to Dr. Robertson, 'twelve Zodiacs were first known in India'. Berjes says that Hindu astronomy is not based on the principles of Ptolemy but the Hindus had acquired enough knowledge of the subject before the Christian Era. Prof. Colebrooke and Weber also support the belief that the lunar asterisms were known first in India.

THE MUSLIM ASTRONOMY :

The Muslim astronomers learnt astronomy from the Hindus and Greeks. They are believed to be the direct discendants of Greek learning as they accepted the astronomical principles propounded by Ptolemy in his 'Syntaxis'. But the Muslim astronomers learnt the astronomical principles of Āryabhaṭṭa I and Brahmagupta before they got acquainted with the theories of Ptolemy. Colebrooke writes in his 'Hindu Algebra' that the Arabs were acquainted with Hindu astronomy even before they learnt about Greek astronomy which is evident from the Arabic

translation of Ptolemy's 'Syntaxis'. Arab astronomers referred Āryabhaṭṭa as Arjabhad, Arjavah or Ajjabhar whom they quoted frequently for his daily motion of the planets. Their Hizri year began in 580 A. D. which is still followed in their lunar calendars.

It is written in the introduction of the 'Astronomical Tables' of Bin al-Admi published in 920 A. D. that during the Califate of Calif Abbadis al-Mansur, a Hindu scholar-astronomer had come to the royal court in 773 A. D. This scholar had brought the tables of the eclipses and instructions (methods) for observing the eclipses and the positions of zodiac signs. Another delegation of Hindu astro-scholars had visited Baghdad earlier in 771 A. D. to introduce Brahmagupta's treatises. His 'Brahmasphuṭa Siddhānta' and 'Khaṇḍa-Khādyaka' were translated in Arabic by the name of 'Al Sind-Hind' and 'Al Arkand'. Later an Arab scholar Ibrahim Ebna Habib al Fazari compiled his tables of Muslim lunar year and lunar months based on the methods of calculation of Brahmagupta. Another group of Indian scientists visited Baghdad in 777-778 A. D. before Yakub Ibn Tariq prepared 'Al Aflaq' tables based on the constant numbers and methods of Brahmagupta.

W. W. Hunter writes in the Asiatic Researches, 'In the eighth century Arab scholars learnt astronomy from India and the principles of Indian astronomy were translated into Arabic in the name of 'Sind-Hind'. It is written in the Arabic book, 'Ain-ul Amba fital Kaluli Atva', 'Indian astronomers taught astronomy and medicine in the royal court of Baghdad in Arab. A scholar named Karka went to the court of King Al Mansur in 772 A. D. to teach astronomy and medicine.'

Famous Arab scholar Alberuni (b. 973 A.D.) came to India with Mahmood Gaznavi. He stayed in India during 1017-1031 A. D. to learn Sanskrit and Astronomy. He translated tables, principles and methods of Hindu astronomy. He wrote that in

astronomy the Hindus were most advanced among all races of the world. The Hindu mathematicians were the inventors of algebra and geometry. According to Dr. Thibaut, 'India is the inventor of original principles of geometry. She had acquired excellence also in ancient times. She used the principles of geometry to pursue this science'. The Algebra of Mohammad Ibn Musa al-Khowarizmi of Baghdad (C. 825 A. D.) which is believed to be the first work to appear under the title of 'algebra' was undoubtedly based on the principles of algebra (Bīja Gaṇita) of Brahmagupta of the seventh century.

ASTRONOMICAL OBSERVATORIES

FROM BAGHDAD TO SAMARKAND :

The Muslim astronomers were zealous disciples. They had a passion far learning and patience for research. Though they learnt astronomy and mathematics from the Hindus and Greeks, they developed these subjects extensively at home. They were keen star gazers who excelled even their masters in observational astronomy. They raised the finest observatories of their times. The notion of increasing the size of the instruments to the maximum extent is undoubtedly of Muslim origin. A number of astronomical observatories consisting of various stone and masonary instruments of huge dimensions, were raised throughout the Muslim World. The Muslim astronomers, thus, started the process of methodical observations during the middle ages.

The fundamental principles of Ptolemy (Almagest) were verified by actual observations at the Baghdad Observatory of Calif Al-ma' mun (813-833 A. D.). An Arc of the Meridian was raised in the Palmyra region in the nineth century. It was used for various astronomical observations. A few accurate masonary instruments adorned the Gondeshapur Observatory which was built in the nineth century. The process of actual observation

continued and a chain of observatories came up in the middle ages. The Cairo Observatory of the tenth century was used for compiling the 'Hakimid Tables'. The observations carried out at the Nishapur Observatory of 1074 A. D. were recorded by al-Khazini for his 'Sanjaric Tables'. Omar Khayyam, the famous Persian poet known for writing tipsy poetry, was also a famous astronomer of Nishapur. He prepared the astronomical tables, reformed a calendar and wrote a book on algebra during the sultanate of Sultan Malik Shah. He also introduced the Jalai Year in 1074 A. D.

Some Arab works mention a few immense instruments of Abul Wafa who made a Sextant of 20 feet radius in 995 A. D. The Sextant of Abu M. al-Khojendi (992 A.D.) was of about 60 feet radius. One of the biggest Muslim observatories was constructed at Maragha in Persia in 1259 A. D. where the famous astronomer Nasir al-Din Tusi (later mentioned by Sawai Jai Singh) compiled his 'Ilkhanic Tables'. He also obtained excellent results by utilising a hole in the dome of a high building.

The Muslims, the builder of the stone and masonary instruments, were equally well versed in making small instruments of metal. Their astrolabe, based on the Ptolemaic theories was improved to the extent that it became an invaluable piece of art and craft besides an efficient and u eful apparatus for making minute astral calculations. The Arabian and Persian works have detailed descriptions of the astrolabes.

Ulugh Beg, the monarch of Samarkand (1393-1449 A. D.), was perhaps the most prominent Turk astronomer. He constructed a large stone and masonary observatory in his capital. Many prominent scholars like Jamsheed al-Kashi (also referred by Sawai Jai Singh), Khadi Zade al-Rumi and Ali al-Qusji were his contemporaries. Ulugh Beg undertook a complete revision of the star catalogue which he based upon his direct observations.

Sawai Jai Singh was familiar with the works of this great Tartar astronomer of Central Asia. The scientific study of astronomy almost ceased throughout the Muslim World with the assassination of Ulugh Beg by his son in 1449 A.D.

ASTRONOMY IN MEDIAEVAL EUROPE :

After the death of Ptolemy in the second century A. D., little progress was made in astonomy for nearly twelve hundred years in Europe. The Catholic church opposed new scientific theories and enlightenment about the concept of the universe and the celestial phenomena. The renaissance of European astronomy took place in the fifteenth-sixteenth centuries. A Polish astronomer Nicolaus Copernicus (1473-1543 A.D.) came out with his bold new book 'De Revolutionibus Orbium Coelestium Libri VI'. He shattered the deep rooted beliefs of the ancients by assigning the central position in the universe to the sun around which five known planets together with the earth rotate in almost circular orbits. He advocated the earth's daily motion on its axis resulting in the apparent rising and setting of heavenly bodies. This was the dawn of modern ast ronomy in Europe.

The discovery of Copernicus set ablaze a chain reaction of scientific research and many astronomical facts were brought to light. Danish-astronomer Tycho Brahe (1546-1601 A.D.) made various astral observations at his large observatory situated on the island of Hven. His observatory continued detailed maps of the stars and motions of the planets. Though the European astronomers adopted some astronomical instruments of the Greek and Arab origin, they did not construct stone and masonary instruments and depended mainly on the metal instruments of smaller dimensions. Following the same tradition Tycho Brahe made some Sextanta and Quadrants, a Parallacticum and the Armillary Sphere. Though opposed to the theories of Copernicus, Tycho Brahe made significant observations which later provided

the basis of his disciple Kepler's new theories. Johann Kepler (1571-1630 A. D.), a German scientist, astronomer and mathematician discovered the theories of planetary motions. He discovered that each planetary orbit is an ellipse with the sun situated at one of the focal points, secondly, the straight line joining the sun and a planet will sweep out equal areas in the same time interval and thirdly, the squares of the periods of any two planets are proportional to the cubes of their mean distances from the sun. Kepler's contemporary Galileo Galilei (1564-1642 A. D.) was a prominent Italian physicist and astronomer who revolutionised the study and research of astronomy in Europe. He constructed and used a telescope for general observation of astral luminaries in 1609 A. D. though the telescopic sights were used later in about 1667 A. D. Galilei's important discoveries include lunar mountain ranges, star clusters, the four brightest satellites of Jupiter and the phases of Venus. Thus, Tycho Brahe Kepler and Galelei preceded Sawai Jai Singh by about a century.

Then came a brilliant British scientist Isaac Newton (1642-1727 A.D.) on the European scene of astronomy. His law of gravitation that every particle in the universe attracts other particles with a force that 'varies directly as the product of their masses and inversely as the square of their distances' forms the basis of celestial mechanics. His three laws of motion which are applied for classical mechanics include the laws of inertia and acceleration and those of action and reaction. Newton's discoveries of the laws of gravitation and motion appeared in his treatise 'Philosophiae Naturalis Principia Mathematica', better known as 'Principia' which was published in 1686 A. D., the year, Jai Singh was born. These laws brought about many developments in astronomical concepts. The Royal Observatory at Greenwich, England, was constructed in 1675 A. D. and it became the line of Prime Meridian (Zero Longitude) for all celestial and terrestrial measurements. Another British astro-

nomer John Flamsteed (1646-1716 A. D.) carried out astral observations with a Quadrant of 3 feet and a Sextant of 6 feet radius. He made extensive observations at the Greenwich Observatory and compiled his famous star catalogue in 1700 A. D. which was by far the most accurate of that time. It was later consulted by Sawai Jai Singh. The French astronomers also took to observational astronomy with the foundation of the Paris Observatory in 1671 A.D. Astronomy was being seriously studied in Portugal also during the late mediaeval ages.

Sawai Jai Singh, the builder of stone observatories in India, was an ardent follower of Hindu traditions of celestial observations which he learnt from the past masters of Indian astronomy. He was, however, influenced by the idea of making large scale masonary instruments of his Arab and Turk predecessors. Most of his masonary instruments are of Hindu origin though they mark a drastic change in size from the earlier metal and wooden devices of much smaller dimension. Some of these 'Jyotiṣa-Yantras' were devised by him and others developed. The influence of European astronomy is not evident in his devices as most of the European knowledge was transmitted to him by Catholic missionaries who opposed new scientific discoveries and secondly most of the contacts he had with Europeans were after he had conceived and accomplished his grand plan of raising five magnificent astronomical observatories in India.

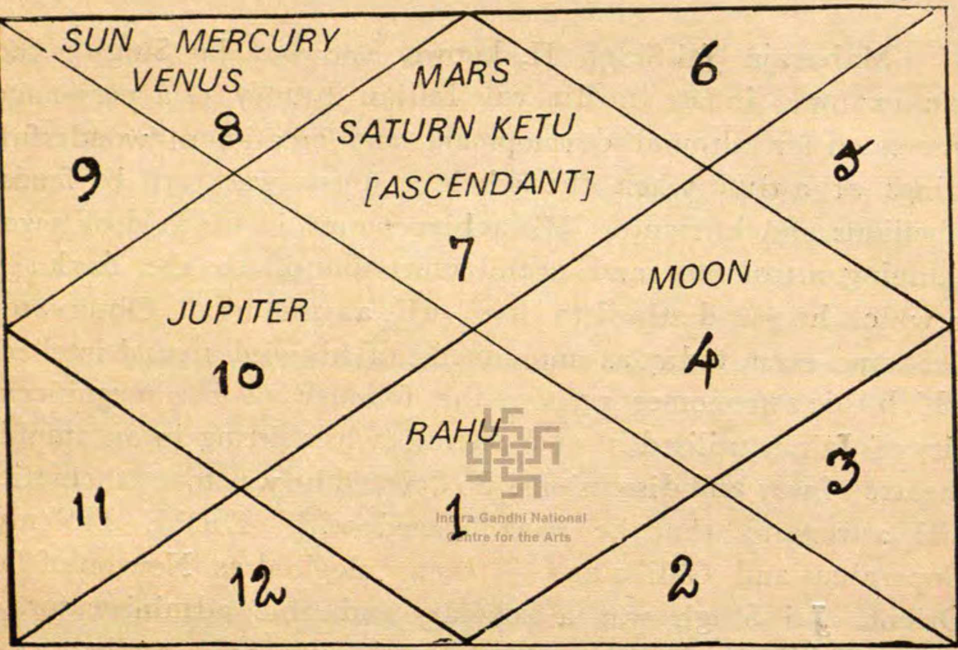
CHAPTER II

I. SAWAI JAI SINGH AND HIS TIMES

Maharaja Jai Singh II, known as Sawai Jai Singh is the sole example in late mediaeval Indian history of a personage who stood for alround development and creation of 'wonderful' things at a time when the whole country was torn by feuds, rebellions and intrigues. His achievements in the field of town-planning, astronomy and architecture illuminate the dark age in which he was destined to live. His astronomical Observatories stand even today as monuments of his wisdom and intellect which this astronomer prince, the founder of the megnificent city of Jaipur utilised in such pursuits while sitting in an amphitheatre of war and dissensions. So devoted he was to mathematics and astronomy that he is compared with Euclid, Ptolemy, Copernicus and Galilei and is even eulogised as Newton of the Orient. Jai Singh was a scholar, and able administrator, a fearless soldier and a shrewd diplomat. He was really a man of genius.

Sawai Jai Singh, born in 1686 A. D. as the eldest son of Maharaja Vishnu Singh (Bishan Singh) of Amber, rose to prominence in early life. A mediator of top rate, he won the hearts of all by his diplomatic moves. By his very unifying nature, he created peaceful conditions in his State. Historians describe him as having won outstanding acclaim throughout the country by his genuis. The Pandits had predicted at the time of his birth that the prince of Amber would be an erudite scholar and would prove to be a 'Jupiter' among the contemporary rulers. This he very well justified and became known all over the world even in his life time.

The palace records at Jaipur preserve the horoscope of the Maharaja, which shows the following combination of the planets at the time of his birth.



The central position of Jupiter (the Planet of Learning) and the second House being occupied by Mercury (the Planet of Wisdom) indicate his passion for mathematics. The Lord of the tenth House is moon in its own House and is lying in the direction of Jupiter. The natural planet of the tenth House is Saturn which is situated in Libra (the ascendant) and is looking towards the tenth House. Saturn (the Planet of Mysticism) is also the Lord of the fifth House and is situated in Libra (the Ascendant). The combination of Moon, Jupiter and Saturn planets indicate that he was destined to study celestial sphere and the heavenly bodies. [The Houses are counted anti-clockwise from the Ascendant in a horoscope].

Jai Singh ascended the 'Gaddī' of Amber in 1699 A.D. when he was only thirteen. He was contemporary of five Moghul emperors, viz., Aurangzeb (1658-1707 A.D.) Bahadur Shah (1707-1712 A.D.) Jahandar Shah (1712-1713 A.D.) Farruksiyar (1713-1719 A.D.) and Muhammad Shah (1719-1748 A.D.). There were bloody feuds for succession and rebellions elsewhere in the country. Jai Singh displayed his prowess, statesmanship and diplomacy of a very high order in his dealings with the Moghuls. He assisted Aurangzeb in his campaign in the South but when Aurangzeb per ued his fanatic and anti-Hindu policies by demolishing Hindu temples, Jai Singh rushed to Mathura and rescued idol of Govind Devji (Lord Krishna) before any harm could be done to it. Aurangzeb, however, was so much impressed by the intelligence, courage and wit of the young Maharaja that he awarded him the title of 'Sawai' which literally means one and a quarter more than his contemporaries. A great diplomat of his times, he also had the courage of a great general. When Bahadur Shah confiscated Amber in 1707 A. D., Jai Singh collected an army of Rajputs and recaptured his capital. It was at this time that he formed a strong league of Rajputs taking with him the Maharaja of Jodhpur and the Maharana of Udaipur as allies. Jai Singh also liberated Ajmer and Sambhar from the Moghuls. Seeing his increasing power and popularity, Bahadur Shah was forced to join hands with him and seek his help in quelling the various rebellions in the country. He also helped Farruksiyar in crushing the rebellion of the Rohillas in Ujjain and another at Bheelsa by killing its chief Dalail Khan.

Sawai Jai Singh was granted the governorship of Agra and Malwa provinces by Emperor Muhammad Shah in 1719. Muhammad Shah was very much impressed by the diplomatic manoeuvres of Jai Singh with the Marhattas and others. On his advice, the Emperor ordered the final rescension of the Jaziya tax which was imposed on the Hindus by Aurangzeb. Jai Singh supressed another rebellion of the Jats at Thun in 1721 A. D. Muhammad

Shah honoured Jai Singh by rewarding him the titles of 'Sar-Samad-e-Raja-e-Hindustan, Raja-e-Rajeshwar, Shri Rajadhiraj Maharaja Jai Singh 'Sawai'. To quote Jawaharlal Nehru, in his Discovery of India, "Jai Singh would have been a remarkable man anywhere and at any time. The fact that he rose and functioned as a scientist in the typically feudal milieu of Rajputana and during one of the darkest periods of Indian history when disruption, war and tumult filled the scene, is very significant."

Indeed, the rise of Sawai Jai Singh on the political and cultural horizon of India during such a time was very sighnificant. Aurangzeb, the last of the great Moghuls, had died in 1707 A.D. and his death had shaken the very foundation of the empire founded by Babur and consolidated by Akbar. Then in 1739 A.D. four years before Jai Singh died, Nadir Shah ransacked Delhi and virtually wiped off all that remained of the once mighty Moghul empire.

During his 44 years of reign, Sawai Jai Singh could employ his mental and physical powers in what turned out to be the most opportune time for his genius. Not only did he dominate the Indian scene in politics and warfare and diplomacy, but he was also able to aggrandise his small principality of Amber to a well defined and extensive 'Raj' stretching from the Jamuna (Yamuna) in the east, to the Sambhar Salt Lake in the West and the Shekhawati region in the North to the natural frontier of the Chambal in the South, while his area of influence extended further south upto the Narmada and even beyond. Nothing happened in India during this period in which Sawai Jai Singh did not have a role and a significant role for that. Not only politics was his sphere, but he equally dominated the social, cultural and literary fields of his time. He was in a sense the maker of his age.

Sawai Jai Singh had inherited a chequered record of Imperial Service from his great ancestors like Raja Bhagwan

Das, Raja Man Singh, Mirza Raja Jai Singh and Maharaja Bishan Singh. These princes of Amber have been rightly described as the pillars of the empire which they conquered, consolidated and governed for their overlords—Akber, Jahangir and Shahjehan. The tolerant and generous policy of these Emperors was, however, abandoned by the bigot Aurangzeb and in consequence there came the turn in the tide. The Moghul crescent which had waxed with loyal and devoted services of the Rajputs began to wane when the Rajputs withheld their help and co-operation, willingly or unwillingly, Jai Singh, the great 'Satrap' of the Moghul court, also became instrumental in the fall of the Moghul hagemony and the rise of the Marhattas, although for most of his life he remained at war wi h the latter.

Inspite of his being 'Satrap' of the empire, it goes to the credit of Sawai Jai Singh that he sought and actually gave an identity and personality to Rajasthan by uniting the Rajput princes and inculcating among them a sense that they were not merely servants of the empire, but lords of their land in their own right. It was because of this policy of Jai Singh that Rajasthan once again rose in its true form of valour and a position of consequence. Both Moghuls and the Marhattas realised in no time that they could neither win nor hold north India without taking the Rajputs with them.

As the great edifice of Moghul empire began to disintegrate and the Marhatta power tried to fill in the void, Rajasthan, with Sawai Jai Singh as the most powerful and influential ruler in the area, also played its role as suited to its interests during that uncertain and trecherous period. Jai Singh not only gained in territory and political power but he gave a new name to his old principality of Amber by founding in 1727 A.D. a new and modern capital Jaipur or Jainagar which is considered to be a model of town planning even today.

The astronomer among princes or the prince among astronomers, as Jai Singh is often described, he lived a full and purposeful life in perfect harmony and tune with his times. The trends he took in politics, in diplomacy, in scholarship, in social reform and in the study of astronomy entitle him to be called, if not a revolutionary, a reformist and a constructive worker who created much out of nothing.

II. HIS STUDY OF THE INFINITE COSMOS

Sawai Jai Singh was a prince and potentate and a scholar and a town-planner, but he entered the gallary of fame in his own right as a devoted student of the infinite cosmos and immortalised himself by his unique contribution to science, particularly to astronomy.

Jai Singh had a sustained, systematic and rational approach to his astronomical studies from the very beginning. He had Pandit Jagannāth, a Mahārashtriān, as his 'Guru' who taught him these subjects. Jai Singh became well acquainted with astronomy and mathematics within a few years. In his court he had a number of scholars and Pandits acquainted with Sanskrit, Arabic, Persian and Greek languages. They translated a number of books from different languages into Sanskrit. Pandit Jagannath impressed the Maharaja by his knowledge of astronomy so much so that the Maharaja awarded him the title of 'Samrāṭ' which is still used by his descendants. Sawai Jai Singh also named the great Sun-Dial as 'Samrāṭ Yantra'. Pandit Jagannath Samrat translated Ptolemy's 'Almagest' from its Arabic version into Sanskrit which came to be known as the 'Samrāṭ' Siddhānta'. Another translation of Ptolemy's 'Almagestri' by him is known as 'Siddhārta Kostubha'. Pandit Kewal Ram of Gujarat was another prominent scholar associated with Sawai Jai Singh. He translated some Latin and other foreign catalogues into Sanskrit, which came to be known as 'Vibhāga Sāriṇī', 'Drak Pakṣa Sāriṇī' and 'Drak Pakṣa Gaṇita'. The translation of Ulugh Beg's works (1393-1449 A.D.) were known as 'Tārā Sāriṇī' and 'Jai Vinoda Sāriṇī'. 'Jai Vinoda Sāriṇī' of Pandit Kewal Ram still serves as the basis of the Jaipur Pañcāṅga (almanac). Another work of Kewal Ram 'Jai Singh Kalpalatā' remained incomplete. Pandit Ratnakar Pundarik and Pandit Vidhyadhar of Bengal were other scholars in the court of Maharaja Sawai Jai Singh.

Jai Singh studied deeply and mastered a number of books on Hindu astronomy. He was thoroughly familiar with the

treatises on ancient Hindu astronomy and mathematics. He studied 'Bṛhat-Jātaka', 'Bṛhat-Saṃhitā' and 'Pañca Siddhāntikā' of Varāhamihira (born 505 A.D.); 'Ārya Bhaṭīya' of Ārya Bhaṭṭa (born 476 A. D.); Brahmasphuṭa Siddhānta' of Brahmagupta (born 598 A.D.); 'Siddhānta Śiromaṇi' of Bhāskarācārya (born 1114 A.D.) and 'Yantra Rāja' of Mahendra Sūri (born 1370 A.D.). He also studied thoroughly the earliest Hindu works on the subject, 'Vedāṅga Jyotiṣa' and 'Sūrya Siddhānta'. He got a famous work on mathematics compiled under the title 'Kṣetra-derśa' about which Sir William Jones says: "The Sanskrit work from which we might expect the most ample and important information is entitled 'Kṣetraderśa' or a view of geometrical knowledge and was compiled in a very large volume by order of the illustrious **Jaya Singha** comprising all that remains on that science in the sacred language of India."

Well-versed in the traditional sources of astronomy and mathematics, he also studied the old Greek treatises such as Euclid's Elements as well as European works on plane and spherical trigonometry and the construction and use of logarithms through their Sanskrit translations by the Pandits and scholars he had collected around him to 'e cape from the labrynth and the precipices of ignorance." He collected treasures of learning from different countries and obtained a thorough knowledge by constant study. Besides Ptolemy's Almagest, the Astronomical Tables of Ulugh Beg, some treatises on the Astrolabe, La Hire's Tabulae Astronomical, Flamsteed's Historia Coelestis Britannica and Euclid's Elements, Jai Singh also mentioned here and there names of the Turk and Arab astronomers like Nasir al-din, al-Tusi, al gurgani and Jamsheed Kashi.

With such intellectual acumen and eagerness to seek the truth, it devolved upon Jai Singh to revive and revitalise the study of Hindu astronomy, reform the Hindu calendar and produce a revised star catalogue and a set of tables of the Sun,

the Moon and the Planets, thus, correcting and improving upon the findings of Ulugh Beg (1393-1449 A.D.) of Samarkand, which according to him, were no longer reliable because correct and actual observations had not been made for nearly three hundred years.

Nevertheless, Jai Singh was quite impressed by the care and the pains taken by the Turk and Persian astronomers in making precise readings and accurate measurements. Although he found the astronomical data handed down by Ulugh Beg as out of date, he adopted much from the system of this royal astronomer of Samarkand, who like Jai Singh devoted himself to the study of the heavens all his life till he was assassinated by his son in 1449 A.D. The astronomical tables of this Tartar astronomer, a grandson of Timur the Lame, which superseded Ptolemy's 'Syntaxis' or 'Almagest' as they are called in Arabic, were adopted by Jai Singh as the basis of his own studies to account for the phenomenon of celestial bodies.

As mentioned earlier, Pandit Kewal Ram translated these famous tables into Sanskrit under the title of 'Tārā Sāriṇī for his royal collaborator. Not only this Jai Singh also used the astrolabe, so familiar with the Arabs and other Muslim astronomers and other similar instruments used by Ulugh Beg. But he soon became suspicious of the brass instruments which, he concluded, could never yield results of high accuracy because of their mechanical imperfections. He, therefore, decided to improve upon the instruments by discarding the metal instruments and pinning his faith on large immovable masonary instruments. He, going by a scale of Asiatic grandeur, chose large and massive stone instruments with generous dimensions to attain greater accuracy and precision with the permission and concurrence of the Emperor of Delhi, Muhammad Shah, then set about erecting his observatories at various chosen places and, thus, establishing a process of check and counter-check of the calcoulatins arrived

at in each of them. He replaced the instruments of metal with those of stone after making experiments with the former as he intended to design his observatories for more versatile use.

The first observatory was completed at Delhi in 1724 A.D. followed by Jaipur about ten years later. Within fifteen years three more observatories were erected at Ujjain, Varanasi and Mathura. Of the five observatories, the one at Jaipur is the largest and complete and still in the best state of preservation. The observatories both at Delhi and Jaipur contain well-known instruments of the older systems as well as Jai Singh's own inventions to meet his greater need for accuracy. Among the latter are the three massive and intriguing edifices—the Samrāṭ Yantra, the Jai Prakāśa Yantra and the Rāma Yantra—the general accuracy of which continues to astonish even modern scientists. W. W. Hunter states : "Jai Singh himself devised the Samrāṭ Yantra, the Jai Prakāśa and the Rāma Yantra. These three instruments are indeed peculiar to Jai Singh's observatories and must be to some extent attributed to Jai Singh's personal ingenuity". The first, the 'Emperor of Dials', is an equinoctial dial with a triangular gnomon flanked on either side by a quadrant of a circle parallel to the plane of the equator. The edges of the quadrants are graduated in hours and minutes as well as in degrees. and each edge of the gnomon was originally traced with two scales of tangents. Solar time, is, thus, given with its day to day variations. After having stood for nearly two hundred fifty years, the 'Samrāṭ' still remains a marvel of accuracy.

The second instrument 'Jai Prakāśa' or light of Jai Singh consists of hemispherical cavities representing half of the celestial sphere with the graduated upper rim of the hemisphere being the horizon. It is an ideal instrument for demonstrating the so-called doctrine of the sphere and showing to the eye the apparant motions of the Sun.

Rāma Yantra, the third invention of Jai Singh used for measuring altitudes and azimuths of the planets and the stars, consists of two circular stone buildings, on the compliment of the other. It was here that Jai Singh made his observations on the basis of which he compiled "Zij-e-Muhammad Shahi", his famous set of astronomical tables so called after the name of the Moghul Emperor, which were virtually a revision and supersession of Ulugh Beg's tables.

Besides these three instruments of his own invention, there are a number of other instruments, all in solid masonry. Some of the important ones among them are the Rāśi Valaya Yantra, a group of 12 instruments of comparatively small size and of the same type as the Samrāṭ, intended for the direct determination of celestial latitude and longitude, the 'Dakṣiṇo Vṛtti Yantra' for obtaining Meridian altitudes and the 'Yantra Rāja', one of the few brass instruments—an astrolabe in all respects such as used by the Tartar predecessor of Jai Singh, which the latter retained with apparent esteem and fascination inspite of his opposition to instruments of metal. He got a book 'Yantra Rāja Kārikā' written to describe its theory and practice. It is a representation of the visible portions of the celestial sphere and solves a large number of problems involving the relations between altitude, azimuth, latitude, longitude, time and position of the heavenly bodies.

Having constructed these instruments, the places of the stars were daily observed and Jai Singh was apparently satisfied with the results achieved. He himself says, "Since in the place by the aid of the unerring Artificier, astronomical instruments have been constructed with all the exactness that the heart can desire and the motions of the stars have for a long period constantly been observed with them."

But, while Jai Singh was thus busy a faint echo of the astronomical advances in Europe reached his ears and his

curiosity which had already collected French and Bavarian Jesuits and Portuguese missionaries around him besides maps and globes of the 'Feringhese' from the English at Surat, could be satisfied only after the procurement of Pere-de-la Hire's tables from Portugal as well as the European tables. There are references of some European astronomers and missionaries whom Jai Singh met and sent abroad to collect more informations.

In 1730 A. D. he met a Portuguese Jesuit Padre Manuel Figuaredo, who was an astronomer and also Padre de Silva who came to Jaipur from Portugal. Jai Singh compared notes with them and then sent some of his astronomer-assistants with them to Portugal to collect more tables, books and latest information about western astronomy. The king of Portugal was very much impressed by the interest and knowledge of the Maharaja and sent one of his astronomers, Xavier De Silva to Jaipur with latest informations and tables.

Muhammad Sharif was sent to some place where the South Pole was over head and Muhammad Mahdi to some other place referred to as 'further islands' to know what was happening there in the field of astronomy. Jai Singh also invited two French astronomer–priests, Father Claude Boudier and his companion from Chandranagor to visit Jaipur and have discussions with him. Other Europeans who came in touch with the astronomer-Maharaja were Father Andre Strobel and Don Pedro de Sylva who was a physician and astronomer. Another French Jesuit Tieffenthaler visited Jaipur in 1743 A. D., the year of Jai Singh's death.

On comparing these various tables with actual observations, he was able to detect errors in the tables of De la Hire, which had been communicated to him by the King of Portugal. He found an error of half a degree on the part of Europeans in assigning the moon's place, as also in other planets. And his conclusion was that since in Europe astronomical instruments have not

been constructed of such a size and so large diameters, the motions which have been observed with them may have deviated a little from the truth."

The observatory of Jai Singh may seem clumsy and out of date now when precision instruments of glass and metal and the telescope are in vogue, but the fact remains that it was unique in its own days. To Jai Singh goes the credit of reviving the Indian system of astronomy and helping the advancement of the most ancient of the sciences "at a time when Europe was still sorting out its ideas and evolving the principles of modern astronomy."

According to Garrett, "We must look upon his labours as the last expiring efforts of the old astronomy as a last and most praise-worthy attempt to probe the mysteries of the universe by the unaided human eye." Wedded as he was to the notion of actual observations, it may well be imagined what exhileration and thrill the 'Super galaxies' and 'Super novae' of today would have had for this devoted student of the infinite cosmos, if he had only known them.

Dr. Zakir Hussain, who unveiled a life-size statue of this astronomer-prince at Jaipur on May 10, 1968, very corrctly observed that Jai Singh possessed the quality of foresight or imaginative anticipation in abundance which manifested itself not only in the city of Jaipur which he planned and actually made from the blue-print, but also in the exercise of his scientific imagination. He had the scientific courage to question the authority of the 'Sūrya Siddhānta' which held sway in India for more than one and a half millenium. He also pointed out the errors in the book of Ptolemy, Hipparchus, Nasir Uddin Tusi, Mirza Ulugh Beg and Mulla Chand Fariduddin Masud, the court-astronomer of Shah Jehan. Having mastered most of them in his youth, he struck upon a common discrepency existing in the works of these masters. The results obtained by

astronomical computation did not agree with the results accruing from mathematical calculations, especially in the case of the Sun and the Moon, the rising and setting of the planets and the eclipses.

The Observatories he built under the expert supervision of Khairullah, the grandson of Ustad Ahmed Nadir Menar, the builder of the Taj Mahal, enabled Jai Singh to find out the causes of this discrepency. Equipped with the kinds of instruments already in use for astronomical observation like the Zatul Halw, the Zatul Sibquatani, the Zatul Shaani, an astrolabe with two rings, the Sadas Fakhsi, invented by Faksud Daulat as the oriental counterpart of the Sextant and the Shamila used by Ulugh Beg in the fifteenth century at Samarkand, these observatories demonstrated the inherent defects of these instruments and led Jai Singh to invent his own instruments already described. As a result of his labours lasting for over a decade, Jai Singh was able to arrive at conclusions which were "crucially significant."

In the course of his mathematical calculations, he found the hypothesis that the orbits of the Sun and the Moon contained two diameters instead of one. Returning to confirm this with his observations, he found the results accrued on the presumption of this hypothesis which meant that the orbits were actually elliptical and not circular.

This, of course, was not a discovery. It had been anticipated by Kepler one hundred years before but it was a new light to which Jai Singh came independently without any knowledge of Kepler's work. Similarly, his discovery of four satellites of the planet Jupiter was also quite independent of Kepler's anticipation. He established that like the Moon, Venus and Mercury received their light from the Sun and that the latter had spots. His calculations of the longitudes of the places he selected for building his observatories also proved to be remar-

kably correct. His observations and astronomical tables still await detailed study by Indian and other astronomers.

The study of astronomy has been universal in all ages and cultures, but it goes to the credit of Sawai Jai Singh that he freed Indian astronomy and astrology from foreign impacts and influences and provided new impetus to their study and research on Indian soil with Indian background assimilating the knowledge from all sources which he could tap in that dark age of Indian history. The synthesis he brought about by adopting a broad scientific attitude is extolled by scientists even to-day.

When Jai Singh was seriously studying astronomy, the astronomers used to prepare the almanacs and calendars on the basis of 23 degrees 35 minutes as the Sun's ecliptic obliquity. Secondly, the stress was more on theoretical calculations than on practical observation in Hindu astronomy. Thus, all astronomical datas and tables were based on mathematical calculations and there were no systematic Observatories for the direct observation of celestial objects and their positions. Thirdly, the Hindu astronomers were not much aware of the progress made and methods adopted in the field of astronomy in other countries. Jai Singh dealt with these problems one by one and gave a turning point to the astronomical studies in India.

Sawai Jai Singh's very first instrument was the Dakṣiṇo Vṛtti Bhitti Yantra or the Meridinal Wall Instrument. With the help of this instrument, he observed the Sun's ecliptic obliquity as 23 degrees 28 minutes (less than half minute of the correct value). He felt the need of reforming the existing tables and almanacs and his revised tables came to be known as 'Zij-i-Muhammad-Shahi' after the Moghul Emperor Muhammad Shah. Its manuscript is available in the City Palace Museum at Jaipur. These tables consist of the names and numbers of stars and constellations, longitudes, latitudes, declinations, magnitudes, right ascension and procession.

Jai Singh was not content with mere study of different astronomical books, consultations with astronomers of various countries and preparation of new tables but he wanted direct observation of celestial bodies and their positions. He spent years studying Hindu astronomy and comparing it with Greek, Muslim and European schools of Astronomy. Subsequently his observatories at five different places of different altitude, latitude and longitude enabled him to compare his observations and ascertain results.

One wonders why Jai Singh constructed his observatories and what was their utility at that time. As already mentioned, before Jai Singh there were no well-established astronomical observatories for the direct observation of celestial bodies to ascertain the results given in the almanacs and star catalogues. Thus, Jai Singh was one of the very few Hindu astronomers to have thought of the need of practical observation of astronomical phenomena with the help of large instruments. Hence the almanacs, Hindu calendars and star catalogues could be prepared to maximum possible accuracy. Secondly, a number of political, social and family events were determined on the basis of astrological calculations which were based on astronomical observations. Thus, his astronomical observatories served as laboratories for the practical study of astronomy and astrology.

While Jai Singh might not have made great astronomical discoveries, he certainly gave a great impetus to the subject and left his everlasting impression on it. His achievements in the field of astronomy may be summed up as follows:

(1) He revived Hindu astronomy to a great extent and stressed the need and carried out practical observations. He was the greatest Hindu astronomer since Brahmagupta of the seventh century.

(2) He revised and prepared a star catalogue, reformed the Hindu calendar and compiled a set of tables of planets

of incredible accuracy which are still used by Hindu astronomers.

(3) He promoted the study of astronomy and mathematics by constructing observatories at five important cities to popularise these studies. He also promoted the study of History and Sanskrit and collected a number of books on these subjects from abroad and elsewhere in the country.

(4) He erected the astronomical observatories which are of great historical and educational value. His observatories are one of the rarest sights and have no parallel the World over. He is the only astronomer in the World to have built as many as five observatories at different places. One does not come across a similar phenomenon in the history of astronomy.

(5) Besides being a great astronomer, the Maharaja was also a town planner and architect of great repute. His mathematical bent is reflected in the lay out of the city of Jaipur which he planned and constructed as his new capital. Jaipur is believed to be one of the best planned cities of the World. To quote Jawaharlal Nehru, "The city of Jaipur was so well and wisely planned that it is still considered a model of town-planning."

Though the probe of the cosmos has reached Olympian heights in our era by man's landing on the Moon and other advanced research of the planets, yet what Jai Singh achieved two and a half centuries ago would never be written off the pages of the history of astronomy. According to Col. James Rod, still the best historian of Rajasthan, 'Jai Singh did in India what Pope Gregory did in England'. His Observatories are monuments which illumine that dark age of Indian history.

Truly, it has been remarked that if Jai Singh had not given his attention to the works of Arabian and European astronomers who preceded and were contemporaries with him, the tradition of astronomical studies in India would not have progressed as it has since his times.

III. SALIENT FEATURES OF HIS OPEN-AIR PLANETARIUMS :

Sawai Jai Singh was contemporary to and associated with five Moghul Emperors. He had to remain occupied with most of the political and military turmoils of his time. Even under such unfavourable circumstances, he snatched time for serious study of astronomy. It is said that this zealous astronomer used to carry the astronomical books and tables whenever he went out of his capital on military expeditions and diplomatic missions. By 1718 he had acquired an extensive knowledge of his most favourite subject by mastering a number of Hindu treatises on astronomy and by consulting certain books on Arabian and European astronomy.

After his extensive studies, Jai Singh came to realise that the Hindu astronomers were the masters of mathematical calculations to determine the celestial phenomenon. They could calculate any astronomical event by mathematical process from a given starting point. This was an important aspect of astronomy but they, however, were not so serious about the practical observations for the study of the celestial spheres. He found some difference in the results arrived at by tabulised calculations and those by actual observations of the same astronomical phenomenon. He was, therefore, not satisfied with the existing astronomical tables. He very well knew that his predecessor Hindu astronomers were great mathematicians who gave the cardinal numerals, zero and decimal system to the world, but they did not, however, put equal emphasis on actual observation for celestial studies. He wanted to give equal importance to practical observation for making the astronomical tables and determining the celestial events. Secondly, he wanted to verify the existing tables by means of actual observations. Thirdly, he wanted to bring Hindu astronomy at par with the western astronomy by erecting astronomical planetariums as the process of systematic

observations had virtually ceased long before him. His views about actual observation are evident in the preface to the 'Samrāṭ Siddhānta'

"In future, who ever be the Lord of the realm, he should assure himself by making enquiries into the motions of the heavenly bodies by making instruments. Reliance should be placed on the results obtained by actual observation taking into account the difference produced by lapse of time or by the irregular movements of the heavens. He, whoever would truly know, should do that, placing reliance on actual observations. For, the true motion of the stars is one thing, and that obtained by calculation from standard works, another. Thus, even in the standard works, the Sūrya Siddhānta and the Brahma Siddhānta, the results do not agree. This shows that the movements of the heavens are not always regular. Actual observations only are reliable yet to suit general requirements and for the use of such as possess not instruments we proceed to give below the old mean method of calculations."

Sawai Jai Singh, thus, realised the need of constructing astronomical observatories to revive Hindu astronomy and to popularise the study of astronomy. He is accredited as the first Hindu astronomer to have thought of the necessity and importance of erecting the astronomical instruments of huge dimensions for practical observation of the celestial spheres, in India. In order to carry out the celestial observations personally, to prepare Hindu calendars, almanacs and ephemeries to maximum possible accuracy and, authenticity, he erected five observatories consisting of huge stone and masonry instruments at five various important places viz. Delhi, the Imperial Moghul capital; Jaipur, his own capital; Ujjain, Varanasi and Mathura, three famous seats of learning and pilgrimage.

The observatories of Sawai Jai Singh are the first and the last of their kind to be built on such a large scale in the country.

These observatories stand even to-day as monuments to the astronomer--Maharaja's scientific approach and great devotion to this ancient science. Jai Singh worked in the true spirit of science and constructed his observatories like an expert scientist, astronomer and architect. His open-air planetariums are unique in the World.

First of all, the blue prints of most of his instruments were made. They were followed by metal and wooden models which can still be seen in the Jaipur Observatory. Most of the instruments were, thus, built on plans and models. The foundations of the instruments are considerably deep which were well built with stone and masonry material. The ground was then levelled by making canals which were filled with water to ascertain the perfect level of the surface on which the instruments were raised later. This was done to avoid the possible impact of earth quakes or trembling of the earth on the planes of the instrument. The instruments which are made in the cavities are interconnected with internal canals so that every drop of rain water collected therein flows out of the Yantras instantly. The Observatories were made at five different places of different altitude, latitude and longitude for comparing and ascertaining results.

Sawai Jai Singh preferred stone and masonry instruments to metal ones. He realised that the metal instruments were less accurate due to the smallness of their size, the want of division into minutes and seconds, the shaking and wearing of their axis, the displacement of the centres of their circles and the shifting of the planes of the instruments. So he built large and massive stone and masonry instruments in order to attain perfect stability with attention to the rules of geometry and adjustment to the meridian and the local latitude etc.

One comes across duplicity of instruments in these observatories. This was done to compare and verify results which

could be attained at more than one instrument by more than one observer simultaneously. Another novel idea of Sawai Jai Singh for observational astronomy is reflected in the construction of two complimentary instruments for the same purpose. These complimentary parts of the Jai Prakāśa Yantra and the Rāma Yantra function round the clock during alternate hours, which was done to facilitate celestial observations. This also exhibites the Maharaja's genius in astronomy and architecture as he could give different shapes to the visible heavens by means of his masonry instruments.

The astronomical instruments in these observatories function round the clock. Almost all instruments are meant for observations both during day and night. On a cloudy or a rainy day, one would find the almanacs and tables handy to arrive at the pre-determined results by mathematical calculations. These observatories served for the actual observation of celestial phenomenon for making the Hindu calendars, almanacs and ephemeries according to which certain forecasts related to the religious and social ceremonies and festivals were made. The auspicious time for coronation, marriage, travel, military and hunting expeditions. construction of forts, palaces and houses and a number of other activities was determined astrologically. Hence a number of astrological interpretations were based on the astronomical data. The horoscopes and forecasts related to weather, eclipses, and other astronomical events were made accordingly. These observatories also served the purpose of education and teaching of practical astronomy. They served as an arena of astronomical discussions where a large number of Pandits (astronomers and astrologers) from different parts of the country would assemble to discuss and exchange views on the subject.

His first observatory was built at the Moghul capital which was often visited by Indian and foreign scholars. His second

planetarium was erected at his own capital where he himself used to make celestial observations. He had also employed a good number of expert astronomers to keep a regular record of the astronomical datas that they would observe every day. Thus, by raising his two observatories at two important places like Delhi and Jaipur, he provided an opportunity to the Pandits attached to the Royal courts to make actual observations and study this science and its practical aspect in a systematic manner.

Then he decided to build his three other observatories in the holy places of great religious significance. Besides, Varanasi, Ujjain and Mathura have also been well known seats of learning. By constructing his Vedhaśālās there he contributed a great deal to the advancement of the study of this ancient science. These three places were also frequented by a large number of pilgrims and many of them were Pandits engaged in the field of astronomy and astrology. Religion and astrology had become inseparable. He, thus, gave a practical turn to what was limited to theory or the texts for the study of this science in its true spirit.

It is interesting to note that Sawai Jai Singh chose the banks of the holy rivers for raising his observatories. His instruments were erected on the bank of the Ganges in Varanasi, on the bank of the Kshipra in Ujjain and on the bank of Yamunā in Mathurā. This would enable a large number of scholars and Pandits to make use of these instruments whenever they went to these rivers for a regular bath or on a pilgrimage. Besides, he preferred such sites in order to have a clear view of the sky for the celestial observations and star gazing. The horizon was also clearly visible from the river banks so the rising and setting of the stars and planets could be easily recorded.

Sawai Jai Singh also decided to construct his observatories on an elevated space. At Varanasi, the observatory was built on the terrace of the Man Madir, the estate founded by his great nacestor Raja Man Singh of Amber. At Mathura also, the

terrace of the Kansa-Kā-Kilā, built by the same ancestor in the sixteenth century, provided the venue. At Delhi and Jaipur where he constructed his observatories on the ground in the heart of the city, he raised lofty instruments in order to have a clear view of the sky and the horizon for the purpose of celestial observations. The Samrāṭ Yantras at Delhi and Jaipur are quite high to facilitate the observations of the rising and the setting of the stars and planets on the horizon and their movement in the visible heavens.

These magnificent Stone-Observatories are a splendour in architecture. Though built nearly two and a half centuries ago, they surprise one with their surrealistic architecture which looks rather ultramodern. These planetariums have been described as "the most surrealistic and logical landscape in stone" as the massive odd-shaped 'Yantras' have a weird look. These observatories are believed to be the largest, the best preserved and the most remarkable of all the ancient observatories existing in the World to-day. These stone observatories are really magnificent and unique in the field of ancient astronomy. A detailed description of his five different observatories follows later.

CHAPTER III

THE OBSERVATIONAL ASTRONOMY : (TECHNICAL TERMS):

Astronomy is the most ancient science in the world. It is the science of observation and determination of the positions, distances, motions, rotations and revolutions of the heavenly objects in the celestial sphere.

The earth is surrounded by stupendous universe which primarily consists of nine planets, thirty one satellites, a great number of stars and some other kinds of celestial objects. The **Pl^nets** are large, solid and almost spherical masses which revolve round the sun in elliptical or almost circular orbits. The planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. Most of the planets are accompanied by smaller objects which are known as moons or satellites which revolve round the planets. All combined, they form the Solar System. Other members of the solar system are **Stars** which are large globes of intensely heated gas and which shine by their own light. The **Sun** is the most prominent star concerning us due to its comparatively closer distance from the earth which gets from it heat and light, the fundamental sources of life.

The earth has an amazingly enormous canopy over it which is known as the **Sky** or the **Celestial Sphere** and all the heavenly bodies seem studded on its interior. There is no such thing in reality as the celestial sphere. It has been imagined as a screen, concave in shape, against which the observer sees the projection of stars and planets and describes their positions. Mere observation of the heavenly bodies gives no idea of their position in

the celestial sphere. Hence for purpose of observation and determination of their position, the celestial sphere is divided into many segmets by different imaginary lines corresponding to the terrestrial lines on the globe. In other words the imaginary lines on the celestial sphere are mere projections of the terrestrial lines extended upto the celestial sphere.

The celestial sphere is divided into two hemispheres. Only one of them is visible, being above the horizon. The **Horizon** is a great circle marking the intersection of the horizontal plane with the celestial sphere.

The apparent celestial sphere is divided into two equal parts, known as the **Northern** and the **Southern Hemispheres** by a great circle, drawn east to west, which is known as the **Celestial Equator.** As the celestial sphere and the terrestrial sphere not only have a common centre but also common axis and a common equatorial plane, the **Celestial Equator** is an extension of the **Terrestrial Equator.** The **Sun** comes on the celestial equator twice in a year, on 21st March and 23rd September which results in the equal duration of day and night on these two occasions. The **Sun** remains in the northern hemisphere from 21st March to 23rd September and in the southern hemisphere from 23rd September to 21st March. On 21st June and 21st December, the Sun comes on the positions extreme north and extreme south of the equator respectively, during its apparent seasonal motion. These positions are known as the Solstices. The Summer Solstice occurs around 21st June which represents the beginning of Summer in the northern hemisphere and the Winter Solstice which occurs around 21st December coincides with the beginning of winter in the northern hemisphere. The summer solstice can also be termed as the point on the ecliptic where the Sun is situated on about 21st June when it has reached its extreme northern declination and is on the Tropic of Cancer. Similarly the winter solstice is the

southern most point on the ecliptic when the Sun reaches the Tropic of Capricorn on about 21st December. In the northern hemisphere summer is the period of the year that begins at summer solstice (about 21st June) and ends at the Autumnal Equinox (about 23rd September). Winter in the northern hemisphere is the period of the year that includes the interval between the winter solstice (about 21st December) and **Vernal Equinox** (21st March).

The axis of the earth extended beyond its North and South Poles is known as the **Celestial Axis.** The two points where it intersects the celestial sphere are known as the **Celestial North Pole** and the **Celestial South Pole.** Their apparent positions in the sky depend on the latitude of the observer's place. People, who live north of the equator can see the Pole star at an altitude above the northern horizon equal to their latitude. But a traveller in the southern hemisphere can see the Pole Star only when he crosses the equator.

Another imaginary circle is drawn across the celestial sphere going through the Zenih, the North and the South Poles and the North and South points on the observer's horizon. This circle is known as the **Local Celestial Meridian** and the heavenly bodies are observed approaching this circle. The Sun comes on the Local Celestial Meridian exactly at Local 12 0' clock every day. The Local Celestial Meridian Circle is used for determining the **Meridian Pass Time** and the **Zenith Distance** of heavenly bodies. **Zenith** is the highest point in the sky directly above the observer. The Local Time is also determined with the help of the Local Celestial Meridian Circle.

Two sets of imaginary circles known as **'Meridians'** and **'Parallels of Latitude'** are used to specify the position of a place on the earth. Similar sets of imaginary circles are drawn on the celestial sphere which are known as **'Hour Circles'** and **'Parallels of Declination'**. In other words, each of the two

hemispheres is divided by drawing circles parallel to the equator which are known as the '**Parallels of Declination**'. They number 90 in each of the two hemispheres, starting with zero from the equator and ending with 90 degrees N. and 90 degrees S. declination for the North and the South Celestial Poles respectively. These circles are used for the determination of the declination of a heavenly body. The **Declination** can be defined as the angular distance of a heavenly body North or South of the celestial equator, measured through 90 degrees from the equator to the pole in a plane perpendicular to the celestial equator.

Another set of circles is drawn parallel to the horizon known as the '**Parallels of Altitude**'. These are used for the determination of the altitude of heavenly objects. The **Altitude** of a celestial body is its angular distance vertically above the plane of the celestial horizon. The **Azimuth** is the horizontal angle between a heavenly object and the South point of the horizon which is measured westward through 360 degrees in a plane parallel to the horizon. Again, each hemisphere is further subdivided by imaginary circles drawn parallel to the equator. These are called the '**Parallels of Latitude**' numbering 90 from the equator to the North Pole and the same number from equator to the South Pole. The Latitude of a celestial object is determined by these circles. **Celestial Latitude** is the angular distance of a celestial body north or south of the ecliptic measured in a plane perpendicular to the ecliptic.

The **Meridians of Longitude** are drawn parallel to the **Prime Meridian** passing through Greenwich, England. Greenwich is also known as the zero meridian or longitude zero degree. The meridians of longitude are also known as the **Hour-Circles** which pass through the North and the South celestial poles. Hour-circles are used to indicate the angular distance of a heavenly body from the zero hour circle. These

circles are used to determine the **Celestial Longitude** which is the angular distance of a celestial object from the vernal equinox measured in a plane parallel to the ecliptic. This term for the stars is known as the '**Right Ascension**'. In the star charts and catalogues, the right ascension and the declination of stars are tabulated.

The great circle which represents the apparent annual orbit of the Sun upon the celestial sphere which is caused by the actual revolution of the earth around the Sun, is known as the **Ecliptic** The great circle of the ecliptic intersect the great circle of the celestial equator at two points which are known as the **Equinoxcs.**

The **Vernal Equinox** is the point of intersection where the Sun changes from South to North declination. The opposite point is known as the **Autumnal Equinox** When the Sun reaches the equinoxes (on 21st March and 23rd September respectively), the days and nights are equal as the term 'equinox' literally means 'equal day and night'.

The equinoxes are not stable points. Each point moves very slowly along the equator and completes one round in about 25,800 years. This movement of the points is known as the **Precession of Equinoxes** The **Precession** is thus the accumulative change in the positions of all celestial objects over a long period of time resulting from the revolution of the earth's rotational axis around the pole of the ecliptic and caused by the gravitational pull of the Sun.

The two great circles of ecliptic and equator do not coincide but intersect each other at two opposite points at an angle of $23\frac{1}{2}$ degrees known as the **Ecliptic Obliquity** which causes the change of seasons on the earth.

The **Zodiac** is a series of constellations along the ecliptic named after living creatures. In the course of a year, the Sun

proceeds through the constellations as follows: Arie—the Ram; Taurus the Bull; Gemini—the Twins, Cancer the Crab; Leo—the Lion, Virgo the Virgin; Libra—the Balance; Scorpius, the Scorpion, Sagittarius—the Archer, Capricornus—the Sea Goat; Aquarius-the Water Bearer; and Pisces—the Fishes.

The Eight –degree wide belt around the ecliptic is called the **Zodiac Circle.** The Zodiac Circle is divided into 12 'signs' of 30 degrees each. The signs, known after the Zodiac constellations, have played an important role in astrology. The Zodiac belt which begins at the varnal equinox includes all the planets visible to the naked eye.

The globular shape of the earth, its diurnal motion on its axis and its annual revolution around the Sun are three fundamental principles which determine the astronomical phenomena. The **Diurnal Motion** is the apparent motion of celestial bodies across the celestial sphere from east to west caused by the earth's rotation on its axis from west to east. This takes 23 hours 56 minutes causing the phenomena of day and night and apparent rising and setting of celestial objects. Another important astronomical phenomenon is the annual motion of the earth round the Sun. The Sun appears to be moving across the celestial sphere. It so appears because earth seems stationary and the Sun seems moving completing the circle every year. But in fact earth moves round the Sun.

These are some of the astronomical phenomena which are observed by astronomers on the celestial sphere which is criss-crossed by a number of imaginary but well defined circles to make the astronomical observations convenient and accurate. The determination of the apparent positions and motions of celestial bodies in the sky is useful for nautical astronomy, celestial navigation, research investigations and surveys. The accumulation of data on celestial positions are required for the preparation of Star Charts and Catalogues, Almanacs, Calendars

and Ephemeris. The astronomical data are also used for astrological studies.

It is fascinating to know that all the well defined celestial circles which are purely imaginary, have been represented in the various astronomical instruments in a rather realistic way. Their portrayal at observatories simply proves that Maharaja Sawai Jai Singh, builder of observatories, was possessed with great knowledge of astronomy. In fact he brought down this celestial sphere on earth and captured it in his stone instruments in perfect reality.

CHAPTER IV

II. THE ASTRONOMICAL INSTRUMENTS OF SAWAI JAI SINGH

The systematic astronomical observatories consisting of huge masonry instruments did not exist in India before Jai Singh, though there are references about a number of Yantras in the ancient Hindu treatises on astronomy as mentioned earlier. The ancient Hindu astronomers knew about the construction of various Yantras for the purpose of astronomical observations of the celestial objects. Sawai Jai Singh studied these Yantras of Hindu origin in detail and learnt the observational methods of the ancients. He also obtained the charts and descriptions of the instruments used by his predecessor and contemporary Turk, Arab and European astronomers. As he preferred the huge stone and masonry instruments to the metal and wooden ones, it seems that he adopted the idea of making large instruments from the Turk astronomers. His instruments are, however, not the reproduction of Turkish and Arabian instruments and he has shown remarkable ingenuity while designing and constructing them. Some of these stone instruments were devised and invented by himself as they are original and have no parallel anywhere else in the World. Other instruments of Hindu origin were developed and perfected by him to such an extent that they reveal his genius and original thinking. A few of his instruments like the Sextant and the Astrolabe have, however, some Turk influence.

1. SAMRĀṬ YANTRA : The Equatorial Dial :

In ancient times, various types of gnomons were described and used by Āryabhaṭṭa, Varāhamihira, Brahmagupta and

Bhāskarācārya. Āryabhaṭṭa described a triangular gnomon and prescribed rules for calculating its area. Gnomons of different kinds were placed in different planes to determine the positions of the heavenly bodies. Another ancient instrument in the form of a triangle was known as the Palabha Yantra as Palabha means the sine of the latitude of the place and, thus, one of the angles of this triangular instrument was made equal to the latitude of the place. Though the triangular gnomon is an ancient type of gnomon in India, the peculiar form of this Yantra—a triangular gnomon in the plane of meridian flanked on either side by two quadrants inclined to the plane of the equator was designed by Sawai Jai Singh. He was assisted by his principal court-astronomer Pandit Jagannath whom Jai Singh awarded the title of 'Samrāṭ'. Though this Yantra has been referred to as the 'Supreme Instrument' or the 'Prince of Dials', it is believed that the Maharaja named this Yantra after Jagannath 'Samrāṭ' whom he considered as his Guru of astronomy. The descendants of Pandit Jagannath Samrāṭ still retain the title of 'Samrāṭ'.

This is the most common instrument erected by the astronomer-Maharaja. Nearly eight such Yantras of different dimensions were built by him at his various observatories. This instrument is in the form of a triangle which makes an angle equivalent to the latitude of the place and is based on the local meridian or in the plane of meridian. This triangular wall is flanked by two quadrants on either side. The quadrants are also inclined by the angle equivalent to the latitude of the place. In other words, the quadrants are made parallel to the hypotenuse of the triangle. Hence they are inclined to the plane of equator or they lie parallel to the celestial equator. Hence the name the 'Equatorial Dial' of the Yantra.

The quadrants are graduated in fifteen 'ghaṭikās' or six hours on each side and the hours are further sub-divided into minutes and seconds. Hence the Yantra is also known as

the 'Equal Hour Instrument' or the Equinoctial Dial. Both the edges of the hypotenuse (gnomon) are graduated in the scale of tangent for measuring the declination. The steps are provided to climb over the gnomon for the purpose of observation of declination. Steps are also provided on either side of the quadrants where the observers could sit, observe and take the readings on the graduated scales.

As already mentioned, the Sun-Dials existed before Jai Singh, but in the construction of Samrāṭ Yantra in this peculiar form, he has shown a remarkable ingenuity. Secondly, the scale of tangent on the gnomon is undoubtedly his own idea as one does not come across the employment of the tangent scales on the gnomons before Sawai Jai Singh.

1 - I. LAGHU SAMRĀṬ YANTRA OF JAIPUR : (Plates No. 2 & 3)

This instrument is in the shape of a triangle. Its hypotenuse make an angle of 27 degrees (26 degrees 57 minutes) with the earth which is its base, situated in the place of local meridian. This angle is equivalent to the latitude of Jaipur. Its vortex makes an angle of 63 degrees while the base with it, makes an angle of 90 degrees. There are steps over the hypotenuse for the purpose of climbing for making certain observations.

A small triangular structure is aligned with the perpendicular wall facing north which also bears the scale markings of angles on both sides of its slope. There are steps provided over this slope as well. This alignment is meant for the observation of certain stars which are near the Pole Star—the stars of less than 27 degrees latitude.

A marble arc is fixed to each side of the perpendicular portion of the instrument. The two arcs of 90 degrees each, having obout 2.5 feet breadth form a semi-circle which is parallel to the celestial equator. In other words, these two quadrants lie in the plane of equator and, thus, are parallel to the hypotenuse.

These two arcs of equal size are stuck on the eastern and western faces of the perpendicular wall of this triangle. These quadrants are graduated on both sides in hours, minutes and seconds. One hour is divided in 60 minutes and one minute in three parts of 20 seconds each. Both sides of the hypotenuse bear the tangent graduations in degrees starting from zero which represents the celestial equator. All these graduations are inlaid with lead in white marble very acurately. There are steps provided on either side of the quadrants which are used to sit while observing the stars and planets during night.

1 - II. BṚHAT SAMRĀṬ YANTRA AT JAIPUR : (Plates No. 4, 5 & 6)

This 'Giant Equatorial Dial' is the biggest 'Samrāṭ Yantra' and the loftiest instrument erected by Sawai Jai Singh. This gigantic structure also happens to be the largest astronomical instrument in the world. The Bṛhat Samrāṭ Yantra is ten times bigger than the Laghu Samrāṭ Yantra (No. 1-I) and as such its each portion is ten times larger in proportion compared to the latter. Both the Yantras are constructed on the same angles and principles.

The instrument is in the shape of a skyscraper triangle. The hypotenuse make an angle of 27 degrees with the base which is situated on the local meridian. This angle is equivalent to the latitude of Jaipur. There are steps over the hypotenuse so that the observer can reach any point on the hypotenuse for the purpose of observations. Its vortex makes angle of 63 degrees while the base with it makes an angle of 90 degrees. The instrument is crowned by a 'Chatrī' (dome) built in typical Rajput style of architecture.

There are two identical quadrants on either side of the wall which is pointing towards the Pole Star. Each quadrant is graduated in 6 hours. Each hour is divided in 60 minutes and each minute is further sub-divided into 30 parts, each

representing 2 seconds. The instrument is thus very accurate and the time calculated on its scale is correct to 2 seconds. Though during day, the time observed is not always correct to 2 seconds due to the lack of sharpness of the gnomon's shadow, falling on the quadrant. But the time calculated during night is correct to 2 seconds as in this process no shadow is involved as explained later.

The channels of mortar and plaster made on the ground also attract the attention of the visitor. These channels were filled with water in order to bring the ground to absolute level on which the 'Bṛhat Samrāṭ Yantra' was to be built. These channels are specimen of the Maharaja's urge for perfection and accuracy while designing and constructing his astronomical instruments.

This triangular instrument of titanic dimensions is flanked by two giant quadrants on its either side which look like the wings of a colossal bird. The gnomon of the instrument is about 90 feet high and its base is streched over 147 feet. The radious of its quadrants is about 50 feet and the quadrants are so enormous (9 feet wide and 78 feet long) that the shadow of the gnomon moves about 13 feet in an hour. This shadow travels about two and a half inches per minute and hence the observer can read the time in minutes and seconds without much difficulty.

The results obtained on this instrument are ten times more accurate than the observations on its smaller version, i. e., the 'Laghu Samrāṭ Yantra', as this instrument is exactly ten times bigger in proportion than the 'Laghu Samrāṭ Yantra'.

A red sand stone circle of 49 feet 10 inches radius is inlaid on a huge platform lying north-west of this Samrāṭ Yantra. Some portion of the circle is graduated in degrees, minutes and seconds. This served as a plan for the Samrāṭ Yantra. This was done to construct and graduate later the huge quadrants of the

'Bṛhat Samrāṭ Yantra' to the maximum possible accuracy. A metal model of the same instrument can also be seen lying on the southern edge of this circle. A wooden model of the same instrument is lying behind the Zodiac Instruments near the southern boundary wall of the observatory.

1 - III. SAMRĀṬ YANTRA AT DELHI : (Plates No 7 & 8)

This is the loftiest instrument of the Delhi Observatory. This is the second highest Samrāṭ Yantra built by Sawai Jai Singh in his five observatories. It is about 70 feet high, 126 feet from east to west and 115 feet from north to south. It is built in a quadrangular excavation which is now filled with water which makes the lower part of the instrument inaccessible for the purpose of observation and calculations.

Like its counterpart at the Jaipur Observatory, this instrument also consists of a triangular wall situated in the plane of meridian of Delhi. Its hypotenuse, which serves as a gnomon, makes with its base an angle of 28 degrees 39 minutes, equivalent to the latitude of Delhi. Thus, the gnomon of the instrument points towards the celestial North Pole.

The triangular structure is flanked by two quadrants each of 50 feet radius. These are made parallel to the hypotenuse and, thus, lie in the plane of celestial equator. The edges of both sides of the gnomon are graduated with the scales of tangent and the quadrants are graduated in hours, minutes and seconds.

1 - IV. SAMRĀṬ YANTRA AT UJJAIN : (Plates No. 9 & 10)

The Ujjain Observatory also consists of a Samrāṭ Yantra or an Equatorial Dial. This Equal-Hour Sun-Dial is made in the form of a triangular wall flanked on either side by two quadrants. The right angled triangular structure is based in the plane of meridian of Ujjain and, thus, points towards the celestial North Pole. The masonry triangle is made parallel to the axis of the earth as it makes with the base an angle of 23 degrees

10 minutes which is equivalent to the geographical latitude of Ujjain. The height of the yantra is 22 feet, its base is 42 feet long and the hypotenuse (gnomon) is stretched over 47 feet. The hypotenuse of this tringular instrument serves as its gnomon which is graduated in the scale of tangent used for the declination readings. Thirty four steps are provided to climb and observe on the gnomon.

Two quadrants of about 9 feet radius are aligned at right angles on either side to the triangular wall and, thus, they lie in the plane of the celestial equator. The quadrants are graduated in hours, minutes and seconds. Three fraction of each minute stand for an accuracy of twenty seconds while making observations of time, zenith distance etc.

1 - V. BṚHAT SAMRĀṬ YANTRA AT VARANASI : (Plate No 11)

This is an Equatorial or Equinoctial Dial consisting of a right angled triangle which makes an angle of 25 degrees with the base situated on the local meridian. It is 23 feet 3 inches high and 35 feet 10 inches long while its hypotenuse (gnomon) is 39 feet 9 inches in length. The masonry triangle is flanked by two quadrants of 9 feet 2 inches radius lying in the plane of the celestial equator. In other words, the quadrants are inclined by 25 degrees and, thus, are parallel to the hypotenuse. The quadrants which are about 6 feet 9 inches wide are graduated in 6 hours on either side. The hour is divided in 60 minutes and each minute is sub-divided into 4 parts of 15 seconds each. The vertical portion of the northern and southern edges of the quadrants bear the 'Ghaṭikā' graduations where $2\frac{1}{2}$ 'Ghaṭikās' are equivalent to one hour, thereby making 1 'Ghaṭikā' equal to 24 minutes. Each 'Ghaṭikā' is subdivided further, the minutest fraction being equivalent to 15 seconds. Elliptical metal plates are inlaid in sand stone quadrants at an interval of half an hour. This was done at the time of restoration to bring in permanency, though three of 24 metal plates have already given

way. The graduations on the quadrants are not in a good state of preservation, though one could read the time etc. to reasonably good accuracy.

One finds the scale of tangent on either side of the gnomon which is approachable by steps. 27 steps take one on top of the instrument which forms the highest point of this observatory from where the observers could observe the rising and setting of stars and planets. This point provides an enchanting view of the holy Ganges flowing below, some of its crowded ghats humming with different religious performances. A portion of the city of Varanasi is also visible from here.

1 - VI. LAGHU SAMRĀṬ YANTRA AT VARANASI : (Plate No. 12)

This is the smallest of all the Samrāṭ Yantras built by the roy 1 astronomer of Jaipur. The small instrument which is 8 feet 2 inches high is situated in the plane of meridian of Varanasi, in a triangular form making an angle of 25 degrees. It's facing exact north. The triangular wall is flanked by two quadrants of 3 feet 2 inches radius. The quadrants which lie in the plane of equator, are 6 feet 3 inches long and 1 feet 8.5 inches wide. These are graduated in hours and minutes which are inscribed in Devanāgarī on the northern edge and in Roman on the southern edge. This seems to have been done at the time of restoration. Each hour is divided in 60 minutes, though the minute is not sub-divided in seconds due to the small proportions of the instrument.

The hyptenuse (gnomon) of the instrument bears the scale of tangents – 60 degrees on either side of the hypotenuse where each degree is sub-divided into 6 parts. The centre bears zero degree representing celestial equator.

Unlike other Samrāṭ Yantras, this instrument does not have steps to climb over its hypotenuse as the observer could make the necessary readings by standing by the side of the instrument

due to its dwarfness. The face of its quadrants and hypotenuse is made of sand stone which bears the smoothered graduations which can be hardly read off now. This also serves as 'Dhruva Darśaka Yantra' to observe the Pole star in the sky.

This instrument was perhaps not meant for the practical observations but simply as a model on the basis of which the bigger Samrāṭ Yantra was built later for practical observations.

1 - VII. LAGHU SAMRĀṬ YANTRA AT MATHURA :

The astronomer Maharaja built a small Equational Dial at his last and smallest observatory at Mathura. No details, however, are available about the dimensions of this Yantra.

THE PURPOSE OF SAMRĀṬ YANTRA :

Local Time, Indian Standard Time, Zenith Distance, Meridian Pass Time, Altitude at Noon and Declination of Stars and Planets are determined with the help of this instrument both during day and night.

OBSERVATION DURING DAY

LOCAL TIME

During day, in Sun light, the shadow of the hypotenuse (its gnomon) falls on the arc in a straight line where the time is graduated on the semi-circular scale of its quadrant. The time can be easily and clearly read off in hours, minutes and seconds where the shadow of the gnomon falls. This is known as the Local Time of the place of observation. The western quadrant works from 6 to 12 O'clock in the morning and its eastern counterpart functions from 12 to 6 O'clock in the afternoon. Exactly at 12 O'clock there will be no shadow on either of the quadrants, as at this hour, the Sun comes on the Local Meridian.

For finding the Indian Standard Time, the Equation of Time is added or subtracted in the mean difference of time and then the result is added in the local time to get the Indian Standard Time. This difference is known as the True Difference for the particular place.

In case of Jaipur, it varies from a minimum of 10 minutes 25 seconds on 5th November every year to a maximum of 41 minutes 6 seconds on 10th February every year, depending on the Mean Difference of Jaipur (— 26 minutes 48 seconds) on the basis of which the True Time is found out.

For the convenience of the readers, four tables giving the difference of time are given herewith. The difference in minutes and seconds between the Local time of Jaipur and other places and the Indian Standard Time which varies from day to day and month to month is given in the following tables. By adding this difference of time to the local time observed on the Samrāṭ Yantra or the Sun-Dial, one can determine the Indian Standard Time easily and accurately. This difference of time is, however, invariable :

(1) The Table of Difference of the Time of Jaipur and the Indian Standard Time :

	5th Min. Sec.	10th Min. Sec.	15th Min. Sec.	20th Min. Sec.	25th Min. Sec.	30th Min. Sec.
January	32.10	34.18	36.13	37.50	39.9	40.8
February	40.52	41.6	41.6	40.38	39.58	39.28
March	38.26	37.15	35.52	34.15	32.55	31.6
April	29.37	28.14	26.56	25.48	28.48	24.2
May	23.28	23.44	23.5	23.15	23.37	24.21
June	25.8	25	26.48	28.12	29.16	30.18

	5th	10th	15th	20th	25th	30th
	Mi. Se.	Mi. Se.	Mi. Se.	Mi. Se.	Mi. Se.	Mi. Se.
July	31.15	32.5	32.39	33.3	33.14	33.8
August	32.46	32.8	31.17	30.12	28.55	27.10
September	25.34	23.52	22.5	20.18	18.34	16.48
October	15.18	13.54	12.39	11.38	10.56	10.28
November	10.25	10.43	11.22	12.24	13.44	15.24
December	17.20	19.18	21.48	24.18	26.48	29.44

The Mean Difference of the Time of Jaipur is -26 min. 48 sec.

(2) The Table of Difference of the Time of Delhi and the Indian Standard Time :

	5th	10th	15th	20th	25th	30th
	Mi. Se.	Mi. Se.	Mi. Se.	Mi. Se.	Mi. Se.	Mi. Se.
January	26.30	28.30	30.33	32.10	33.39	34.28
February	35.12	35.26	35.21	37.58	34.18	33.48
March	23.46	31.35	30.12	28.35	27.15	25.26
April	32.57	22.34	21.16	20.8	19.8	18.22
May	17.48	18.4	17.25	17.35	17.57	18.41
June	19.28	19.20	21.8	22.32	23.36	24.38
July	25.35	26.25	26.59	27.23	27.34	27.28
August	27.6	26.28	25.37	24.32	23.15	21.30
September	19.54	18.12	16.25	14.38	12.54	11.8
October	9.38	8.14	6.59	5.58	5.16	4.48
November	4.45	5.3	5.42	6.44	8.4	9.44
December	11.40	13.38	16.8	18.38	21.8	24.4

The Mean Difference of the Time of Delhi
is -21 minutes 8 seconds.

(3) The Table of Difference of the Time of Ujjain and the Indian Standard Time :

	5th Mi. Se.	10th Mi. Se.	15th Mi. Se.	20th Mi. Se.	25th Mi. Se.	30th Mi. Se.
January	32.18	34.26	36.21	37.58	39.17	40.16
February	41.00	41.14	41.9	40.46	40.6	39.36
March	38.34	37.23	36.00	34.23	33.3	31.14
April	29.45	28.22	27.2	25.56	24.56	24.10
May	23.36	23.52	23.13	23.23	23.45	24.29
June	25.16	25.8	26.56	23 20	29.24	30.26
July	31.23	32.13	32.47	33.11	33.22	33.18
August	32.54	32.16	31.25	30.20	29.3	27.18
September	25.42	24 00	22.13	20 26	18.42	16.56
October	15.26	14.2	12.47	11.46	11.2	10.36
November	10.33	10.51	11.30	12.32	13.52	15.32
December	17.28	19 26	21.56	24.26	26.55	29.52

The Mean Difference of the Time of Ujjain is –27 minutes.

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(4) The Table of Difference of the Time of Varanasi and the Indian Standard Time :

	5th Mi. Se.	10th Mi. Se.	15th Mi. Se.	20th Mi. Se.	25th Mi. Se.	30th Mi. Se.
January	3.26	5.36	7.29	9.6	10.25	11.24
February	12.8	12.22	12.17	11.54	11.14	10.44
March	9.42	8.31	7.8	5.31	4.11	2.22
April	0.53	–0.30	–1.48	–2.56	–3.56	–4.42
May	–5.16	–5.36	–5.39	–5.29	–5.7	–4.23
June	–3.36	–3.44	–1.56	–0.32	–0.32	1.34

	5th Mi. Se.	10th Mi. Se.	15th Mi. Se.	20th Mi. Se.	25th Mi. Se.	30th Mi. Se.
July	2.31	3.21	3.55	4.19	4.30	4.24
August	4.2	3.24	2.33	1.28	0.11	–1.34
September	–3.18	–4.52	–6.39	–8.26	–10.10	–11.56
October	–13.26	–14.50	–16.5	–17.6	–17.48	–18.16
November	–18.19	–18.1	–17.22	–16.20	–15.00	–13.20
December	–11.24	–9.26	–6.56	–4.26	–1.56	1.00

The Mean Difference of the Time of Varanasi is plus 2 minutes 8 seconds.

ZENITH DISTANCE AND MERIDIAN PASS TIME :

The situation of the central wall is on the local meridian. In day time, the shadow of the Sun is visible on either of the quadrants. The distance between the shadow on the quadrant and the central wall would be the Zenith Distance of the Sun.

For example, if the shadow of the gnomon is visible at 10 0'clock, the di.tance from 10 0'clock to the central wall is equal to 2 hours or 30 degrees. That means that the Sun is 30 degrees away from the Zenith and that it would reach the Zenith after two hours.

This is also termed as the Meridian Pass Time, i.e. 12 0'clock when the Sun crosses the Local Meridian. According to the above cited example, the Sun would pass the Local Meridian after two hours. When the Sun goes west of the Meridian, the eastern quadrant is used for observations. By observing the shadow of the gnomon falling on the quadrant, one can find as to when the Sun passed the meridian or when it will pass the same. The Sun comes on the Local Meridian at 12 0'clock (local time) every day, irrespective of the place and season.

ALTITUDE OF THE SUN :

The altitude of the Sun can not be determined directly on this instrument and therefore an indirect method of calculation is adopted. At noon, the declination of the Sun is observed on the basis of which the altitude of the Sun is found out by calculations.

Declination of the Sun + Latitude of the place = Zenith Distance of the Sun.

90 degrees — Zenith Distance = Altitdude of the Sun

For example, if the declination of the Sun on 22nd December is 23 degrees 27 minutes as observed on the Samrāṭ Yantra at Jaipur and the latitude of Jaipur is 27 degrees. The declination of the Sun is then added to the latitude. The result thereof would be (23 degrees 27 minutes + 27 degrees =) 50 degrees 27 minutes. This result is the Zenith Distance of the Sun. Now this Zenith Distance is subtracted from 90 degrees and the result there of (90 degrees — 50 deg. 27 min. =) 39 deg. 33 min. would be the altitude of the Sun at noon on the day of observation at Jaipur.

DECLINATION :

The celestial equator divides the sky into two equal parts, known as the northern hemisphere and the southern hemisphere. When a planet is in the south of the celestial equator, it is said to be in the southern hemisphere and when it is north of the celestial equator it is said to be in the northern hemisphere. The distance in degrees of the planet from the equator in the southern or the northern hemisphere is known as the declination which can be calculated with the help of this instrument. The observer has to go up the steps on the hypotenuse (gnomon). Then a sharp pointer — or even a pencil is placed on the graduated edge of the hypotenuse.

The pointer is placed at such a point on the graduated scale that its shadow intersects the shadow of the gnomon already

falling on the quadrant. The intersection has to be taken in account only when it is at the edge of the quadrant (marble arc). The pointer should be displaced for attaining perfect readings.

The intersection of the shadows is noted on the southern edge of the quadrant when the Sun is in the northern hemisphere and when the Sun is in the southern hemisphere, the intersection is noted on the northern edge of the quadrant.

Reading on the gnomon is taken from zero at a place where the pointer stands, intersecting the shadow below. This will be the angle of declination of the Sun at the time of observation.

If the same observation is done on 23rd September and 21st March when the Sun comes on the celestial equator, the pointer would be invariably placed at zero-without showing any declination.

OBSERVATION DURING NIGHT : The Time :

This instrument is also used during night to know the Time. It is always the Indian Standard Time which is known with the help of certain stars, i. e. Aldebaran, Antares, Scorplii, Altair, Arcturus, Vega, Tauri, Capella, etc.

First of all, the observer should know the Meridian Pass Time of the particular star. The particular star is then looked at by keeping the eye on either southern or northern edge of the quadrant depending on its hemispherical position, in such a way that the particular star seems touching the hypotenuse of the triangular instrument. At this time, the distance between the point where the eye is touching the quadrant and the central wall is read in hours, minutes and seconds on the graduated arc. By adding or subtracting this reading from the Meridian Pass Time of the same star, the Indian Standard Time is found out. It is subtracted if the western quadrant is used and added when the eastern quadrant is used for observations.

Example :

In the night, a particular star, by the above mentioned method, is observed by keeping the eye at 9 0'clock. That means the star will come on the local meridian after 3 hours. Now, if the Meridian Pass Time of this star is 11 0'clock, the observed time would be 11 – 3 = 8 0'clock.

Before Meridian Pass Time, the particular star is observed from the west of the central wall and after the Meridian Pass Time the same is observed from the east of the central wall. If a paticular star is looked at by keeping the eye at 3 A. M. on the quadrant and the Meridian Pass Time of the same star is 11 0'clock, the time observed would be 11+3=2 A.M. I.S.T.

ZENITH DISTANCE AND THE MERIDIAN PASS TIME :

The zenith distance of planets and stars is measured during night by observing the stars by keeping the eye on the southern or the northern edge of the quadrant in such a way that the particular star seems touching the hypotenuse. The distance between the position of the eye and the central wall would be the zenith distance of the particular star in hours and minutes and also in degrees as one hour is equivalent to 15 degrees on the quadrant.

Example :

If the star is being observed by keeping the eye on 9 0'clock marking the distance between the place of eye and the central wall would be 3 hours. This would be known as the zenith distance of the particular star as this star would pass the meridian after 3 hours — at that time this star can not be seen from either of the quadrants by the above mentioned method. The zenith distance could also be referred as 45 degrees in the same case.

Declination :

This instrument is used to measure the angle of declination of planets and stars. The particular heavenly body is looked at by keeping the eye on the quadrant in such a way that it appears touching the hypotenuse. Now another observer is required to climb the steps on the hypotenuse and put a pointer on the graduated edge of the hypotenuse in such a way that now the particular heavenly body is not visible to the person making observations from downstairs. That means the heavenly body, the pointer and the eye of the first observer-all three fall in a straight line. This alignment can also be arranged with the help of a thread, one end of which is tied with the pointer to be kept on the edge of the gnomon (hypotenuse) and the other to be kept where the eye is set on the edge of the quadrant, thus, to bring the particular heavenly body under observation in the same straight line. To use the thread for this purpose was a common practice in ancient observatories.

The position of the pointer or the thread on the graduated edge of the gnomon gives the angle of declination of the same heavenly body under observation. For this purpose the eye is kept on the northern edge of the quadrant if the particular planet or star is in the southern hemisphere and on the southern edge of the quadrant if the same is in the northern hemisphere.

1 - A. MISCELLANEOVS INSTRUMENTS :

1. THE 'CHATRĪ' (THE BELVEDERE) AT JAIPUR

The giant Equinoctial Instrument is crowned by a 'Chatrī' (dome). One has to scale one hundred steps to get there to have a bird's eye view of the Observatory and the neighbouring city complex. This panoramic view provides a feast to the eye. In the north one sees the City Palace complex, the ramparts and fortification, the Tiger Fort, Ganesh Temple on the hill, Water Palace and the Water Supply System (Laxman Doongri) and Sawai Man Singh Town Hall which is currently being used as the State Legislative Assembly. Towards east, the Sun Temple crowning the hill and the back of the facade of the Palace of the Winds are prominently visible. When one turns towards the west, the Victory Tower and the Hathroi Fort invite one's attention and towards the south the Albert Hall and the Moti Doongri Castle (Takht-e-Shahi) are the principal sights. The complex of great many houses crowned with domes, kiosks and cupolas built in the typical style of Hindu and Persian architecture provide a fascinating view.

On looking down from the 'Chatrī' one gets altogether a different view of the astronomical instruments. They have a great fascination around them due to their odd designs and surrealistic architecture which makes the whole Observatory look like a fairy land. The 'Samrāṭ Yantra' looks really like a 'Samrāṭ' (king) as it dwarfs all the instruments of the Observatory.

As this is the highest point in the Observatory and the major part of the horizon is also visible from here, the place is also used for observing the rising and setting time of different stars and planets.

The 'Chatrī' being the highest point in the city in the days of the astronomer-Maharaja and even afterwards was used for announcing celestial notices to the masses. A drum was beaten

on the 'Chatrī' to announce the start of an eclipse. Another beat of the drum would sound the end of the eclipse. This was particularly done to acquaint people with the exact beginning and end of an eclipse as Hindus suspend all their mundane activities during the time they are under the impact of an eclipse. The people usually sit at rest or give alms to the poor or chant prayers to God during the eclipse. The 'Chatrī' had thus great significance.

WEATHER FORECAST BUREAU :

THE 'PAVANA-DHĀRAṆA' CEREMONY (Plates No. 13 & 14)

The 'Chatrī' was also used as a place to ascertain the weather and calculate the data for future forecasts. At sun set hour on 'Āṣāḍha-pūrṇimā' (full moon night of the Hindu month 'Āṣāḍha') — also known as the 'Guru Pūrṇimā' which falls in late June or early July every year, Pandits (astronomers) go up the 'Chatrī' with a muslin flag to determine the direction of the wind. They would hoist the flag adjacent to the wall below the 'Chatrī' where two round shaped stones are fixed to hold the pole (flag) vertical.

This would usually be the season to welcome the monsoon in this part of the country. The Pandits studied changes in weather, direction of movement of clouds and their colour at the time of sun-set and other astronomical phenomenon as related to drift of the monsoon to analyse their studies and chalk out a forecast about the frequency and quantity of rainfall, wind storms etc. for the ensuing year. The flag would give the direction of the wind on which the forecasts were based.

Even today some expert Pandits of Jaipur (Pandit Kalyan Dutt Sharma being one of them) go up the Bṛhat Samrāṭ Yantra at sun-set on 'Āṣāḍha pūrṇimā' to study the metereological changes and make weather forecasts. The results of their

studies are included in the 'Pañcāṅgas' (Hindu calendars and almanacs) which are used by the people. The colourful ceremony of flag hoisting is watched by a large number of people especially the traditionalists of the Pin City. The month 'Āṣāḍha' has been chosen for studies as it is during this month when generally the monsoon is expected to break in this region. The month has great significance in classical Indian literature for its association with the clouds and rains. Kālidāsa wrote about 'Āṣāḍha' in his famous 'Meghadūta.'

There are different interpretations of the directions of wind according to which weather forecasts are made. Here are some for example :

Direction of the Wind	Interpretation
1. 'Pūrva' (East)	Good rains, good crops.
2. 'Agni' (Between East and South)	Less than normal rains, windy days, sand storms, danger from fire.
3. 'Dakṣiṇa' (South)	Scarcity of rains, famine.
4. 'Nairṛtī (Between South and West)	Less than normal rains.
5. 'Paśćima' (West)	Heavy rains, floods.
6. 'Vayu' (Between West and North).	Scattered rains windy days, sand and wind storms.
7. 'Uttara' (North)	Plenty of rains, good crops.
8. 'Īśāna' (Between North and East).	Very good rains, exceptionally good crops.

The 'Megha Mahodaya' of Megha Vijayagaṇi contains similar interpretation of 'Pavana Dhāraṇa' (the direction of the wind) for predicting weather :

"To know the good or bad ensuing year, certain natural symptoms should be observed on the full moon evening of the month of 'Āṣāḍha'. If the easterly breeze blows at the time of the sun set, various crops are richly harvested on the earth. The breeze coming from 'āgnaiya' (south-east corner) direction indicates the spread of epidemics. Southern wind predicts feuds, unheavals and clashes between the states. 'Nairṛtya' (south-west corner) wind is the harbinger of drought and famine. Hence it is advisible to stock the grains. Plenty of rains result in rich harvests following the westerly breeze. 'Vāyavya' (north-west corner) wind forecasts the nuisance of locust, insects and mosquitos in the following months. The breeze coming from the north and 'Īśāna' (north-east corner) direction brings abundance·and prosperity and happy and peaceful days."

"Kādambinī' of late Pandit Madhusudan Ojha of Jaipur gives similar descriptions for forecasting weather and crops:

"One should observe the wind direction on the eve of the full moon night (Āṣāḍha Pūrṇimā). If the wind is flowing from the east, north or 'Īśāna' it indicates good time ahead in the form of good rains and rick harvests. If the direction of the wind is 'āgnaiya' 'nairṛtya', or 'vāyavya', it might lead to drought and famine. The western and southern wind results in about half of the normal harvests."

This was, however, observed to have a general idea of the ensuing mansoon. More detailed and exact forecastes were based on the transition of stars, placements of planets, the colour of the sky and clouds at dawn and dusk and some other minute observations of the·celestial sphere. Some metereological forecasts based on similar observations and calculations are still made by Pandit-astrologers from time to time.

2. ṢAṢṬHĀṂŚA YANTRA : The Sextant (The Pin-Hole Instrument) :

Turiya Yantra (the Quadrant) was used in ancient India to determine altitude of the heavenly bodies at their meridian

pass time. The altitude in degrees was then deducted from 90 degrees to know the zenith distance. The zenith distance was then added or subtracted from the latitude of the place to know the declination. There were, however, no instruments in India in the shape of a sixty degree arc to determine the celestial declinations of the astral bodies directly on the graduated dial. It seems that Sawai Jai Singh adopted this particular instrument from the Samarkand Observatory of Mirza Ulugh Beg (1393-1449 A. D.) which had a lofty masonry sextant. Sawai Jai Singh was acquainted with the tables and instruments of this famous Turk astronomer of Central Asia as mentioned earlier.

2 - I. THE SEXTANT AT JAIPUR

On either side of the 'Bṛhat Samrāṭ Yantra' there are two rooms covered from all sides. One does not imagin that they have inside them instruments known as Ṣaṣṭhāṁśa Yantra. Only one of the two instruments is kept open for observers these days. It is on the western side of the 'Samrāṭ'.

On either side of the rectangular room there are scales in the shape of graduated arcs of 60 degrees each. They are so fixed to the opposite walls that their entire surface faces the ceiling. Two very small orifices are kept in the ceiling through which the sun light from over the open roof passes. The adjustment of these 'pin-holes' is made as such the sun light falls directly on the graduated arcs. The whole construction and adjustment is so accurate that the rays of the sun fall on scales only at mid-day when the sun comes on the Local Meridian. In other words, like Bhitti Yantra, this instrument is also situated on the meridian.

The Sextant consists of two graduated arcs made parallel to each other. Towards the wall, there are graduations of degrees for the direct observation of declination where zero represents the celestial equator. There are graduations of 23 deg. 27 min. representing the Obliquity of the Sun, north and

south of the equator. Each degree here is divided in 10 minutes and each minute is further divided in 6 parts. The outer scale towards the edge of the quadrant bears graduations of zenith distance. 26.56 degrees, the latitude of Jaipur, coincides with the zero (the celestial equator) on the inner scale. It gives the minimum Z. D. as 3.5 degrees on the 22nd June to a maximum Z. D. as 50.4 degrees on the 22nd December marking the Summer and Winter Solstices respectively. The Z. D. is always counted from the southern end of the Sextant arc marking zero, which represents the Zenith. Each degree here is divided in 10 minutes of 6 parts each. Hence each small fraction represents / 1 'Kalā' or 1 minute.

2 - II. THE SEXTANT AT-DELHI :

The eastern quadrant of the Samrāṭ Yantra is supported by a chamber which contained another instrument known as the 'Ṣaṣṭhāṁśa Yantra the Sextant Instrument-consisting of a graduated arc of 60 degrees for the observation of meridian altitude of the sun which shines through the tiny orifices provided above the arc, as and when it crosses the local meridian exactly at mid-day. The chamber containing this instrument is closed now and the Sextant is inaccessible. Unlike two Ṣaṣṭhāṁśa Yantras built on either side of the Samrāṭ Yantra at Jaipur, only one Ṣaṣṭhāṁśa Yantra was made at Delhi.

2. PURPOSE :

Latitude of Jaipur, Length of Day, Rising and Setting Time, Zenith Distance and Altitude of the Sun at Noon are determined on the basis of direct observation of Declination of the sun at noon with the help of this instrument during day.

Zenith Distance, Altitude, Length of Night, Rising and Setting Time of Stars and Planets are determined on the basis of their Declination at their Meridian Pass Time with the help of this instrument during night.

OBSERVATION DURING DAY :

The Sun-light is observed in this instrument when it falls on the curved scale at local 12 0'clock when the sun comes on the Local Meridian. Exactly at mid-day the sun light falls on the scale through the pin-holes above. It can be seen moving slowly on the scales. The centre of this round spot of light is marked on the scale and is counted from zero degree. This reading in degrees and the part thereof would be the declination of the Sun at noon. On the basis of declination, the altitude of the Sun can also be calculated. The latitude of Jaipur is also measured on the basis of declination.

It may be again mentioned that the latitude of Jaipur (26.56 deg.) is fixed but it is calculated only to verify other observations. The time of Sun-rise and Sun-set, the length of day etc. are also determined with the help of calculations on this instrument. For more details the description of Dakṣiṇovṛtti ; Bhitti Yantra (The Meridinal Wall Instrument No. 7) may be referred to.

OBSERVATION DURING NIGHT :

By knowing the Meridian Pass Time of planets, the declination is observed on this instrument during night. When planets pass the Local Meridian, their rays fall on the curved scales in the dark room. The rays of Moon Jupiter and Venus are visible on this sextant though the rays of other planets are rather faint. The centre of the spot where the rays fall is marked and measured in degrees from zero degree to find the declination of the particular planet at its Meridian Pass Time. The altitude of the planet, its rising and setting time, the length of night etc. are determined by similar calculations as described for the Dakṣiṇovṛtti-Bhitti Yantra (No. 7).

3. THE HORIZONTAL SUN-DIAL AT JAIPUR :

On top of the Nārivalaya Yantra a different type of Sun-Dial is situated. As the base of this instrument is made parallel

to the horizon this Yantra is known as the Horizontal Sun-Dial. A triangular metal gnomon of 27 degree inclination is provided at the Centre of the Yantra exactly in the plane of local Meridian. The base of the Yantra is graduated in 30 'ghaṭikās' representing 12 hours as one 'ghaṭikā' is equivalent to 24 minutes. The shadow of the gnomon is observed on the graduated dial to determine the local time and the Meridian Pass Time of the sun. This instrument is a specimen of the Sun-Dials used in the forts and palaces in olden days. An identical Sun-Dial is also available on the terrace of the old Amber Palace near Jaipur.

4. THE HORIZONTAL SUN-DIAL AT DELHI :

65 Steps take one on the top of the gnomon of the Samrāṭ Yantra where a round and thick pillar is erected. A horizontal Sun-Dial is made on the top of this round structure. This dial is meant for the observation of local time of Delhi during day and night. During day the shadow of the gnomon falling on the graduated dial indicates the time whereas at night the time is known by observing the Meridian Pass Time of certain prominent stars. The particular star is looked at by keeping the eye on the graduated edge of the pillar in such a way that the Star under observation seems touching the gnomon of the horizontal dial. With the help of its Meridian Pass Time the time can be known by calculations. The horizontal Sun-Dial is placed on a raised pillar to facilitate such observations.

5. THE HORIZONTAL SUN-DIAL AT MATHURA :

A similar horizontal Sun-Dial was available at the Mathura Observatory also when it was intact.

6 THE HORIZONTAL SUN-DIAL AT UJJAIN :

A horizontal Sun-Dial is placed on top of the Meridinal Wall Instrument in the Ujjain Observatory. The marble dial is of about $1\frac{1}{2}$ feet diameter and is graduated in hours from 6 O'clock in the morning to 7 O'clock in the evening. At its centre a tri-

angular metal gnomon making an angle of 23·10' with the dial is placed accurately in the plane of meridian. Its shadow is recorded on the graduated dial to determine time.

7. DIK-SĀDHANĀ YANTRA AT UJJAIN

This was made of a water level cistern constructed between the Nārivalaya Yantra and the Samrāṭ Yantra. The object of this Dharātala Yantra was to ensure the evenness of the plane parallel to the horizon before making and measuring the angle of latitude of the gnomon of the Samrāṭ Yantra and the dial of the Nārivalaya Yantra.

8 ŚAṄKU YANTRA (GNOMON) AT UJJAIN (Plate No. 15):

The Śaṅku Yantra is a unique feature of the Ujjain Observatory. This Yantra was, however, not originally built by Sawai Jai Singh but is a later addition done to the Vedhaśālā under the supervision of a learned scholar G. S. Apte. The Gnomon Instrument is used to know the direction, time and the relative position of the observer on the earth. It consists of a circular platform of 22 feet 8 inches diameter in the horizontal plane of Ujjain and a 4 feet high Śaṅku (gnomon) which is placed at right angles at its graduated in 360 degrees, each of six parts.

Seven red sand-stone stripes paved from the centre of the platform indicate the west and north directions. They represent different tropical signs and the shadow of the gnomons travels along them on particular days of the year. On the equinoctial days (21st March and 23rd September) when the day and night are of equal duration, the shadow of the gnomon coincides with the straight red line representing the celestial equator (Tropical Libra and Aries) as marked on the platform. The latitude of the place can also be calculated with the help of the shadow of the gnomon at noon on either of these equinoctial days then the shadow travels on this equinoctial line only.

Two red stripes towards the extreme North and the extreme South represent the Tropical Capricorn (Sayana Makara) and

the Tropical Cancer (Sayana-Karka) respectively and consequently the shadow of the gnomon travels on these on 22nd June and 22nd December respectively. One of the two lines drawn from the Tropical Capricorn towards the Celestial Equator represents the Tropical Aquarius and Sagittarius. It attracts the shadow of the gnomon on the 20th January and 22nd November. The other line adjoining to it represents the Tropical Pisces and Scorpio which gets the shadow of the gnomon on the 18th February and 23rd October. Similarly the first line South of the equator stands for the Tropical Taurus and Virgo which gets the shadow of the gnomon on the 21st April and 23rd August. The second line South of the equator is meant to attract the shadow of the gnomon on the 21st May and 23rd July as this line stands for the Tropical Gemini and Leo.

The apparent local time of any moment can be determined by calculating the Zenith distance of the sun with the help of the shadow. The altitude and azimuth of the sun can also be found out with the shadow as the basis. In case of the other celestial bodies too, the altitude and azimuth can be found by necessary observations.

The elliptical red lines on the platform indicate the length of day as well as the position of the shadow on the dates mentioned above. The shape of these lines proves that the orbit of the earth around the sun is elliptical.

2. DHRUVA DARŚAKA YANTRA : The Pole Star Instrument : at Jaipur

Towards east, near the Laghu Samrāṭ Yantra, stands the Dhruva Darśaka Yantra – another triangular instrument which is only meant to have a view of the Pole Star. The wall facing north is at 90 degree angle to the base which provides a 27 degree elevation to the hypotenuse meeting the highest point of this instrument.

The Pole Star is one of the most prominent heavenly bodies and is of great astronomical significance. This star has been a guide to astronomers, navigators and observers for centuries together. It is the pivotal point around which a number of astronomical observations revolve. The determination of direction, local meridian line, meridian circles and the latitudes of places, the ecliptic circle and a score of other astronomical activities are observed and calculated from this pivotal point. Besides its astronomical significance, the Pole Star has some mythological significance to Hindus. Therefore, the construction of an instrument devoted to the Pole Star only had all the more meaning for the Astronomer-Maharaja who was classical in his very nature.

OBSERVATION :

To locate the Pole Star, the observer places his eye down the elevated hypotenuse. His eye is placed at this angle so that the entire view is seen through the slope of the hypotenuse. At far end he will find the Pole Star glittering in the sky. This instrument is so fixed facing the north and so angularly constructed that the Pole Star is made visible without any difficulty.

3. NĀRIVALAYA YANTRA : The Sun-Dial :

This is a simple astronomical instrument of Hindu origin commonly used by ancient astronomers. A number of ancient treatises on astronomy often refer to this dial for simple astronomical observations. Varāhmihira mentions about a gnomon which was placed in various planes for observing its shadow. Bhāskarācārya describes his 'Nārivalaya' as a circle of wood whose circumference was graduated into 'ghaṭīs' and its sub-divisions. This dial was placed in the plane of equator and

a vertical gnomon was fixed at its centre. The shadow of the gnomon was taken into account to determine Local time and hemispherical positions. This Yantra was also known as a 'Dhūpa Ghaḍī' or the Sun-Dial.

Sawai Jai Singh improved his Yantra to a considerable extent. He made it of bigger dimensions in stone. He made the dial inclined to the plane of celestial equator, thus, dividing the heavenly sphere into two equal parts, viz., the northern and southern hemispheres. The gnomon is vertically fixed on the equatorial dial pointing towards the celestial north and south poles. Its shadow is observed as it falls on the dial graduated in 'ghaṭikās' or in hours and minutes. This is used to determine local time to compare and verify it with the readings obtained on other instruments.

3 - A. NĀRIVALAYA YANTRA AT JAIPUR : (Plate No. 16)

This Yantra is a circular Sun-Dial. It consists of two dials, one facing the north and the other facing the south, which are used for the observations of respective hemispheres. The tilt of the southern dial is 27 degrees which is equivalent to the latitude of Jaipur. The northern dial also make an equal angle. Both dials are parallel to each other and lie in the plane of celestial equator. Thus, they divide the heavenly sphere into two equal parts, viz., the northern and the southern hemispheres. A big metal pointer, pointing towards the Pole fixed at right angles at the centre of both the dials and it serves as a gnomon.

The circumference of the dial is graduated into 24 hours each of 60 minutes. The innermost circle is divided into 'ghaṭikās' and 'palas' dividing 24 hours into 60 parts of 'ghaṭikās' where each 'ghaṭikā' represents 24 minutes. In the middle circle, one hour is divided into 12 parts of 5 minutes each. The diameter of this Yantra is about 10 feet.

3 - B. NĀRIVALAYA YANTRA AT UJJAIN :

Sawai Jai Singh constructed a small Nārivalaya Yantra at his Ujjain Observatory also. Like its counterparts at Jaipur and Varanasi, this Sun-Dial also consists of two circular dials which are made parallel to each other. The inclination of the dials is 23 degrees 10 minutes and, thus, they lie in the plane of celestial equator. They divide, consequently, the heavenly sphere above Ujjain in two equal parts viz., the northern and the southern hemispheres. This happens to be the smallest of all the Nārivalaya Yantras erected by the astronomer-prince of Jaipur. This is in the form of an oblique cylinder which is 7 feet 6 inches long and 3 feet 7 inches in diameter. The diameter of the graduated dial is, however, 1 feet 9 inches only. The dials are graduated in hours and minutes - from 5 0'clock in the morning to 7 0'clock in the evening – where one hour is divided into 20 parts of 3 minutes each. Originally the dials were graduated in 'ghaṭikās'.

An eight inch long metal gnomon is provided vertically on the northern dial. The similar vertical gnomon on the southern dial is however, missing rendering the dial unserviceable. The shadow of the gnomon(Śaṅku) as it falls on the graduated dial is taken into account to show the difference of time, i.e., the hour angle and also the true time of the day. As this Yantra also indicates the passage of the sun accross the celestial equator, it is also termed as the Gola Yantra or the Hemisphere Indicator.

3 - C. NĀRIVALAYA YANTRA AT VARANASI : (Plate No. 18)

This Yantra is also known as the Dakṣiṇo and Uttara Gola as both sides of the instrument are facing the southern and northern hemispheres. The Dial is made inclined to the plane of equator and thus is inclined by 25 degrees, the latitude of Varanasi. The circumference of the dial is graduated in 24 hours in Roman numbers. Hours are then subdivided into

minutes to the minimum of 1 minute. The inner circle of the dial has 'ghaṭikā' graduations where each 'ghaṭikā is divided into 6 parts of 4 fraction each which is also equivalent to 1 minute. Its diameter is 4 feet 7 inches. An iron pointer of $5\frac{1}{2}$ inches is fixed vertically on the dial.

The dial facing the southern hemisphere is not well graduated though one finds almost the same markings of hours on the outer circle and of ghaṭikās on the inner portion of the dial. The diameter of this dial is 2 feet 2 inches. A $4\frac{1}{2}$ inch long pointer is provided at the centre of the dial and it serves as its gnomon.

3 - D. NĀRIVALAYA YANTRA AT MATHURA :

No detailed information is available about the Mathura Observatory but it contained the Sun-Dial in the form of a Nārivalaya Yantra which was one of the commonest instruments employed by Sawai Jai Singh in his observatories.

PURPOSE :

This instrument is used to find out the hemispherical positions of planets and stars. As a sun-dial this also serves to determine the Local Time and the Meridian Pass Time and the Zenith Distance of the Sun.

OBSERVATION DURING DAY AND NIGHT :

This instrument is used for knowing the hemispherical positions of the heavenly bodies both during day and night. When the stars and planets are visible from the southern dial of the instrument, it indicates their position in the southern hemisphere and when the planets and stars are visible from the northern dial of the instrument, it indicates their situation in the northern hemisphere.

EXAMPLE :

When the sun remains in the northern hemisphere from 21st March to 22nd September, it can be seen from the northern

dial only and from 23rd September to 20th March, when it remains in the southern hemisphere, it can be seen from the southern dial only. The sun comes on the equator on 21st March and 23rd September every year when its shadow can not be seen on either of the two dials. The Sun is looked at by standing infront of the dial in such a way that the spinal cord of the observer touches the dial. This way, when the Sun is in the northern hemisphere it can not be seen from the southern dial from morning to evening for six months and vice-versa. Similarly other planets and stars are observed from both of these dials to know their hemispherical position during night.

LOCAL TIME AND M. P. T.

During day, the Local Time is also observed on this instrument by seeing the shadow of the big rod (its gnomon) falling on the dial which is graduated in hours and minutes. Both dials function for six months each according to the hemispherical situation of the Sun. The Meridian Pass Time (M.P.T.) of the Sun can also be measured by this instrument by observing the shadow of the gnomon, east or:west of the meridian. That would also indicate the zenith distance of the Sun at the time of observation.

4. KRĀNTIVṚTTA YANTRA : (The Ecliptic Instrument) :

Sawai Jai Singh designed this unique instrument with the help of his astronomer - assistants for his royal observatory at Jaipur. Ancient Hindu astronomers were well-versed in calculating the longitude and latitude of planets by mathematical process but they did not, however, possess any Yantras for determining the longitudes and latitudes of the planets directly on the instruments. This instrument is quite significant as it provides direct readings of the longitudes and latitudes of the heavenly objects. Sawai Jai Singh installed the Krāntivṛtta Yantra, the only instrument of its kind, at his personal observatory at Jaipur.

4. KRĀNTIVṚTTA YANTRA AT JAIPUR : (Plate No. 19)

The Krāntivṛtta Instrument is small but has a rather unique place in this observatory. It has no peer among all other observatories set up by the royal astronomer-Sawai Jai Singh.

The instrument has a masonry base. On its north side a stone-circle is fitted in such a way that it lies accurately in the plane of equator, thus making an angle of 27 degrees. There is a metal rod fixed at the centre of the stone-circle. This rod serves as centre for another circular metal frame which rotates over the stone base for the purpose of observation.

The metal-circle has two handles on either side by which it is rotated. The stone-circle is, graduated in 'ghaṭikās' totalling 60 which are equivalent to 24 hours. Each 'ghaṭikā' is sub-divided into 6 parts. As one 'ghaṭikā' is equivalent to 24 minutes, each small part is equal to 4 minutes. The small part is further sub-divided into 3 parts, each representing 4/3 minutes, i. e. 1 minute 20 seconds.

The metal frame consists of two metal circles, joined together at an angle of 47 degees which is double of the ecliptic obliquity. It is due to this double-obliquity angle that the observations of planets both in the northern and southern hemispheres is possible on this instrument. The upper metal-circle is the ecliptic circle which can be easily adjusted so as to represent the ecliptic at any time of observation. This metal circle is graduated in 360 degrees, each degree being sub-divided into 6 minutes. The metal circle is rotated and adjusted over the stone circle with the help of two handles for direct observation of the actual position of Capricorn point from the meridian.

PURPOSE :

The Longitude and the Latitude of planets in degrees, minutes and seconds, at any time during day and night, are directly measured with the help of this instrument.

The longitude is easily found out but it is only the tropical reading in which by deducting the 'ayanāṁśa' (precession), it tallies with the reading given in the calendars and almanacs based on Hindu system of astronomy.

OBSERVATION DURING DAY AND NIGHT :

On the day of observation, first of all, one has to find out the Meridian Pass Time of the beginning point of the ecliptic circle by means of calculations with the help of ephemeris. By adding 17 hours 57 minutes to this time, one can know the Meridian Pass Time of the beginning point of the sign of Capricorn. The difference of the Meridian Pass Time of the beginning point of Capricorn and the particular time of observation will indicate as how many hours and minutes, after or before, the starting point of Capricorn will come on the meridian. Then, from the mark of 60 'ghaṭikās' which represents the meridian position, the metal circle is displaced back and forth and fixed according to this difference. In this position the instrument will be in the plane of the ecliptic.

EXAMPLE :

Supposing the starting point of Capricorn came on the meridian at 4 0'clock. By adding 17 hours 57 minutes (which is the difference of M.P.T. of the beginning point of Aries and M.P.T. of the beginning point of Aries and M.P.T. of the beginning point of Capricorn) to this, we get 9:57 P.M. when the beginning point of Capricorn will come on the meridian. Now, if the observation time is 10: 1 P.M., the difference remains only (10:1 P.M – 9:57 P.M. =) 4 minutes. Therefore, the point of Capricorn on the instrument must be moved 4 minutes from 60 'ghaṭikā' mark towards the west. If the observation time is 9:53 P.M., then also the difference remains (9:53 P.M. – 9:57 P.M. =) 4 minutes. This time the difference is –4 minutes and, therefore, in this case, the point of Capricorn will be moved and fixed at 4 minutes from 60 'ghaṭikā' mark – but towards the east.

Thus, if the observation time is a few hours and minutes before the Meridian Pass Time of the beginning point of Capricorn, the instrument is displaced towards the east of 60 'ghaṭikā' mark. If the observation time is after the Meridian Pass Time of the beginning point of Capricorn, the circular instrument is displaced towards the west of the 60 'ghaṭikā' mark and fixed in accordance with the difference of time. After this a metal tube is attached in the hole made at the centre of the metal circle and displaced in such a way that the particular planet is clearly visible by seeing through the tube. The tube is held at the point where the particular planet is visible through this and its reading is taken on the scale graduated on the metal circle. This reading in degrees and minutes, is the longitude of the planet under observation through the tube.

This reading is tropical, so the 'ayanāṁśa' (precession) is deducted from this tropical reading to find out the 'niryan' (without precession) according to Indian System.

LATITUDE OF PLANETS :

Except the Sun, all the planets circle in their respective orbits. The latitude of the Sun is not visible because the orbit of the Sun is its ecliptic circle as well and, therefore, the distance between these two orbits is always zero. But the other planets that move in their respective orbits make the latitude from the ecliptic circle as the latitude of a planet is the distance in degrees of its orbit from the ecliptic circle.

The latitude of the planets is observed by this instrument always north-south or parallel to the meridian. For this particular observation, an external right-angled instrument, attached at the upper end of the tube is used. The small instrument is known as the 'Turiya-Yantra'. The planet under observation is looked at through the tube as mentioned earlier by adjusting upward this triangular attachment on the tube in such a way that the particular planet becomes clearly visible. The reading

in degrees of the displacement of the tube on this small right-angled attachment would be the latitude of the particular planet under observation.

Sawai Jai Singh, in fact, planned to make use of this instrument in a far more exact method. For this he wanted an instrument of large proportions. He did order its construction. The very first instrument, one comes across on entering the observatory, is a reminder of the Maharaja's ambition. It has a huge masonry dial of about 10 feet diameter. It has a metal rod at its centre. Its circumference is also graduated. But it could not be completed. According to experts its construction was abandoned as it involved problems for observers rather than solving them. On such a huge dial they would have needed the metal ecliptic circle of the same proportions. It was uphill task to construct it and then to rotate it for the purpose of observations and measurements. So its huge shape would have proved a problem instead of being a boon for exact observations. Instead an instrument of smaller proportions was constructed which has been described above. The incomplete huge structure of 'Krāntivṛtta', however, still stands.

5. YANTRA RĀJA : The Astrolabe : (Plate No. 20)

Yantra Rāja–the King of Instruments–is believed to be of Arab Origin. The Arab astrolabe was initially based on the theories of Ptolemy, which was improved almost to perfection by the Muslims in the tenth-eleventh centuries. It was a very popular instrument with the Muslim astronomers who exercised considerable ingenuity in designing and improving various types of the astrolabe. Some of their astrolabes became valuable work of art and craft besides being an efficient instrument of observation and calculation.

Some Persian and Arabic works describing the theories of astrolabe were written in the eleventh century. Though the earliest work on the astrolabe in India was by Mahendra Sūri

(1370 A. D.), the principles of the astrolabe were not new to ancient Hindu astronomers. The astrolabe existed in the form of a 'celestial map' as evident from the ancient Hindu treatises. Bhāskarācārya's 'Phalaka Yantra' consisted of a board divided by horizontals into 90 equal parts. Some other lines depicting various astronomical circles were drawn. It was vertically suspended by a chair for the purpose of celestial observations.

Bhāskarācārya prescribed the measurement of such an instrument. A rectangular board, 90 'aṅgulas' (finger-width) wide and 180 'aṅgulas' long was suspended vertically with the help of a chain. The Board could be rotated as and when required. The instructions further continued about graduating different astronomical circles on it. A peg was fixed at its centre. Another flat rod (about 60 'aṅgulas' long one 'aṅgula' wide and half 'aṅgula' thick) with a hole at its middle, was then attached to the peg provided at the middle of this rectangular Yantra so that it could be displaced whenever so required. The board was placed in front of the Sun in such a way that the light of the sun fell on both of its surfaces. The shadow of the gnomon falling on the graduated board would give the altitude and other readings. The heavenly bodies were observed with medium of the outer end of the rod which could be displaced on this celestial map.

5. I YANTRA RĀJA AT JAIPUR (Plate No. 21)

The 'Yantra Rāja' hangs perpendicular in the east of the 'Krāntivṛtta Yantra' (No. 4). 'Yantra Rāja' literally means the 'King of Instruments'. It is an ancient type of astrolabe which was a very favourite instrument with the astronomer-Maharaja. Sawai Jai Singh had such a fancy for it that he wrote in Sanskrit a detailed book entitled 'Yantra Rāja Kārikā' in two volumes on this instrument. The book finds its place in the library of the City Palace, Jaipur. Even today the instrument has its pride place in astronomy with the living astronomers and astrologers of India because of its elaborate calculations.

The functions of this instrument are so complicated that a volume can be written discussing and explaining them from A to Z. Hence a brief desciption of the instrument is given here.

This instrument is in the shape of a big metal dial of about 7 feet diameter which is mistaken for a big dinner - gong of the days of yore. But on approaching near it evidently appears to be a cob-web of straight and circular astronomical lines.

This huge dial has a hole at its centre which represents the Pole Star. 27 degrees below this point a curved line is drawn east to west which represents the horizon of Jaipur. Parallel to the horizon, the altitude circles are drawn at a distance of 6 degrees each upto the zenith which is northern most point of the meridian line. The meridian line runs through the Pole from north to south. Other lines on the dial represent hour angles, prime vertical, tropic of Cancer, tropic of Capricorn etc. The ecliptic circle is also depicted on the dial. There are two graduated circles near the circumferences of the dial. The outer circle is graduated into 60 'ghaṭikās', further divided into 6 degrees each. The inner circle is divided into 360 degrees, each further sub-divided into 6 degrees. Some prominent stars are also located on the dial each being at the difference of their respective declination. Name of these stars are engraved on the dial. They include Samudra Pakṣī (Ceti), Rohiṇī (Tauri), Lubdhaka (Canis Majoris), Ārdrā (Orionis) Puṣyā (Cancri), Maghā (Leonis), Hastā (Corvi), Citrā (Virginis). Svāti (Bootis), Anurādhā (Scorpii), Abhijit (Lyrae), Śravaṇā (Aguilae) Satyajīva (Aguilae) and Pūrvabhādrapada (Pegasi).

The instrument is also provided with an ecliptic circle which is attached at its central hole (North Pole) for the purpose of observation. This separate ecliptic circle is movable and can be rotated about this point as and when required. The circumference of this ecliptic circle is graduated into 12 zodiac signs at a difference of 30 degrees each. Thus its point 12 repre-

sents the First Point of Aries, point 9 indicates the First Point of Capricorn, point 3 represents the First Point of Cancer and so on.

PURPOSE :

The altitude, Zenith Distance, Declination and Longitudes of planets and stars ; the local time, the Ascendant, the 4th, 7th and 10 Houses of the Zodiac etc. are determined with the help of this instrument. The instrument has multi-purpose use in astronomy as is evident from special attention paid to it by Maharaja Sawai Jai Singh.

OBSERVATION DURING DAY AND NIGHT :

ALTITUDE :

A hollow tube is attached at the centre of the instrument. During day, if the altitude of the Sun is to be found out, the instrument, hanging in a perpendicular form, is so rotated that its shadow forms a straight line. This would be the position in which the instrument falls in the plane of meridian. Then the tube is so displaced that the Sun becomes clearly visible through it. The position of the tube is demarcated on the dial. This point is measured from the line of the horizon to yield the altitude.

At night, the particular planet or the star is looked through the attached tube by displacing it on the dial until the particular planet or the star is clearly visible through the tube. At that place the tube is fixed tight. The reading of its position on the graduated dial would be the altitude of the particular heavenly body.

LOCAL TIME :

This instrument does not give the time directly. For finding the Local Time, it is essential to know the longitude of the Sun and other planets. In this process an external metal circle is fixed at the centre covering the ecliptic circle in such a way that the degrees of the Sun's longitude (at that time)

should lie on the east point of horizon in forenoon and on its west point in the afternoon. Then the reading of the Beginning Point of Capricorn (270 deg.) of the external metal circle is marked on the circular scale on the dial.

After that the altitude of the Sun is found out. Then the Sun's longitude point is moved on the dial and fixed at the altitude point. Due to this displacement, the Capricorn point will also shift to a different point which is marked on the scale. Now the second place of the point of Capricorn in hours and minutes will be the time from Sun-rise.

EXAMPLE :

For finding the time on this instrument, it is very important to know the time of Sun-rise and Sun-set. By deducting the Sun rise time from 12 0'clock the time of Sun-set is known and vice-versa.

If the difference due to the displacement on the ecliptic circle comes to 2 hours 10 minutes and the time of observation is before noon on the day of observation, the Local Time can be found by adding the difference (2 hrs. 10 min.) to the time of Sun-rise. If this observation is done on 21st March when the Sun-rise time is 6 0'clock, the local time at the moment of observation would be (6 hrs. + 2 hrs. 10 min. =) 8 0'clock 10 min. in the morning. The Indian Standard Time can be known by calculating this according to the True Difference as already explained in the function of 'Samrāṭ Yantra'. In the after-noon, the observation time, according to the difference on the scale, is deducted from the time of 'Sun-set.

For finding out the Sidereal Time, the ecliptic circle should touch the First Point of Aries on the circle on extreme east or west. Then the counting is taken upto point 9 in order to know the Sidereal Time and for Local Time, degrees of longitude are used.

By similar process, the Time can be determined during night also. In this case, it is necessary to know the rising and setting time of the particular planet or the star.

ZENITH - DISTANCE :

To know the zenith distance, the altitude of the Sun at noon is deducted from 90 degrees. In the night, the planets and stars come on the meridian at a particular time. At this time, their altitude is found out. Then, this altitude in degrees is deducted from 90 degrees to know the zenith distance of a particular planet or star.

DECLINATION :

The zenith distance in degrees at the Meridian Pass Time is either deducted from or added to the local latitude (27 degrees) to know the declination of stars and planets.

LONGITUDE :

The real position of planets in the sky is also determined with the help of this instrument. This is found out by astronomical calculations after knowing the declination of the particular heavely body. There is also a direct method for the determination of longitude of planets but it would need volumes to explain that.

ASCENDANT, 4TH, 7TH AND 10TH HOUSES OF THE ZODIAC :

For the preparation of a person's horoscope at the time of birth, it is necessary according to Indian System to do the calculations of 12 parts of the zodiac circle. In such calculations, the main thing is to know the 4th, 7th and the 10th Houses of the zodiac for astronomical calculations. When this calculation is done on this instrument at the time of one's birth, the reading of ecliptic circle on the perpendicular line will indicate the 10th House; its reading on the downward line crossing the central point will show the 4th House; its reading on the eastern horizon will

indicate the Ascendant and its reading on the western horizon will give the 7th House. All these observations may be verified by detailed mathematical calculations later. Thus, the horoscopes can be chalked out in an easy yet authentic manner.

6. UNNATAṂŚA YANTRA : The Altitude Instrument :

The Unnataṁśa Yantra is a kind of 'Śaṅku' (gnomon) placed in the vertical plane for altitude measurements. It is an instrument of Hindu origin which was frequently used by astronomers in ancient India. Varāhamihira laid down rules for making an Unnataṁśa Yantra in the sixth century. According to his description in the 'Pañca Siddhāntikā', this circular instrument was made of either wood or metal. Its diameter was of one 'hasta' (about 1.5 feet) and thickness of about half an inch. Its circumference was graduated in 360 equaldegrees. A hole was provided at its centre where a peg (gnomon) was fixed while making the observations. It was suspended vertically in order to rotate it as and when required. The astral body was looked at by keeping the eye on the graduated circumference with the medium of the peg fixed at the centre. The position of the eye on the circle would give the altitude of the celestial object.

Sawai Jai Singh followed the same instructions for making his Unnataṁśa Yantra though he made it on a much larger scale for more accurate readings. This is the only instrument of this type built by the royal astronomer for his personal observatory and is available only at Jaipur.

6- I UNNATAṂŚA YANTRA AT JAIPUR : (Plate No. 22)

This instrument hangs vertically in the form of a big metal circle of about 18 ft. diameter on a masonry support. The circle is divided into four segments of 90 degrees each. It bears on its circumference the markings of degrees and minutes as each degree is sub-divided into ten parts. There is a hole in the centre of this circular instrument where a pointer is attached at

the time of observation. For the purpose of observation, the whole instrument can be rotated about its vertical diameter. The circular masonry steps are provided around the instrument for observation even from the lower part of the instrument. The entire construction around the instrument is as such that observations can be made by standing at any point.

This is one of the few metal instruments made by Sawai Jai Singh on the traditional line of observation as prevalent in ancient studies of astronomy. The Maharaja had first made experiments with the metal instruments. But after keen observations of the heavenly bodies with their assistance he realised that certain readings at metal instruments yielded somewhat faulty results. As a result he made an all masonry instrument named as 'Rāma Yantra'.

In fact, the Unnataṁśa Yantra and the Rāma Yantra stand for the same purpose of reading of altitude. However, the latter has some sophistication as described elsewhere in the book.

The Unnataṁśa Yantra was considered as a bit less perfect for observing the altitudes of planets mainly because it is all a rotating instrument and as such, can easily be held at one point for making exact measurements.

PURPOSE :

This instrument is used for finding the altitude of planets and stars-both during day and night.

OBSERVATION DURING DAY :

For finding out the altitude of the Sun during day, this instrument is revolved and placed at such an angle that it makes its shadow in the form of a straight line. In this position this instrument will lie in the plane of meridian of the Sun.

A pointer is then fixed in the central hole of the instrument. Keeping this pointer as the middle spot, the Sun is looked at by keeping the eye on the edge of the circular scale in such a

way that all three—the Sun, the pointer and the eye, fall in one straight line. The position of the eye as measured on the edge of the circle will be the altitude of the Sun in degrees and minutes. During the forenoon period, the altitude is considered from the eastern horizon while in the afternoon it is counted from the western horizon.

OBSERVATION DURING NIGHT :

This instrument is also used during night for measuring the altitude of planets and stars. As at night the shadow of the instrument cannot be observed in the form of a straight line, this instrument, therefore is moved and rotated in such a way that it falls on the meridian circle of the particular heavenly body being observed. The pointer is then fixed in the centre and with its medium the same heavenly body is looked at by keeping the eye on the edge of the circular scale in such a way that all three—the pointer, the heavenly body and the eye, fall in one straight line. The position of the eye on the circular scale would be the altitude of the observed planet or star in degrees and minutes.

7. DAKṢIṆOVṚTTI BHITTI YANTRA :

(The Meridinal Wall Instrument) :

To observe the shadow of the mid-day Sun with the help of a Yaṣṭi or Śaṅku (gnomon) was an old practice with the astronomers in ancient India. The Meridinal wall instrument is the improved and vertical version of the same Yantra though its real identity is found in the Turiya Yantra (the Quadrant Instrument) of Brahmagupta who devised this Yantra in the seventh century A. D. Brahmagupta also referred to a 'Dinārdha Yantra' or the Mid-Day Instrument for similar meridinal observations. The western face of the Bhitti Yantra at Jaipur consists of a graduated semi-circle but only its northern quadrant functions as the shadow of the gnomon does not fall

on the southern quadrant due to Jaipur's situation in the northern hemisphere. This is the true replica of the Turiya Yantra of the ancient Indian astronomers. An improved version of the Quadrant Instrument was also described by Bhāskarācārya in his treatise, the 'Siddhānta Śiromaṇi' of the twelfth century A. D. The eastern face of the instrument that consists of two quadrants intersecting each other are also based on the principle of the ancient Turiya Yantra.

7 - I DAKṢIṆOVṚTTI YANTRA AT JAIPUR : (Plate No. 23)

A : The Western Face of the Instrument :

This instrument is situated in the north of the Bṛhat Samrāṭ Yantra, the biggest instrument in the observatories of Sawai Jai Singh. A huge wall, accurately placed in the plane of meridian forms the base of this instrument which is absolutely vertical. It is known as the Dakṣiṇovṛtti Bhitti Yantra or the Meridinal Wall Instrument. A semi-circular marble scale of 19 feet 10 inches radius is the western face of the instrument. The base of this semi-circle is on the top, at the centre of which an iron peg (pointer) is fixed at right angle. Its shadow is observed when it falls on the semi-circular scale. The semi-circle is graduated in 180 degrees and each degree is further divided into 10 parts. The work of graduating the marble scale is excellently and flowlessly done by inlaying degrees and minutes with lead which reminds the visitors of the Moghul inscriptions.

The steps are provided on both sides of the arc, thus, making every inch of the scale accessible for the observer for calculations. The shadow of the iron peg never touches the graduated portions of the semi-circular scale except at local 12 0'clock when the Sun comes on the Local Meridian.

B. The Eastern Face of the Instrument : (Plate No. 24)

The eastern face of the Dakṣiṇovṛtti or Dakṣiṇodak Bhitti Yantra at Jaipur has a similar instrument. This Yantra consists

of two quadrants of 90 degrees each and of 20 feet radius, intersecting each other at 60 degrees. The marble quadrants are graduated in degrees. Each degree is divided in 10 parts and each part is further sub-divided in three fractions, each representing 2 minutes. The wall which forms the base of this instrument lies in the plane of meridian. Two iron pegs are provided on top of each arc for the observation of their shadow that falls on the graduated arcs below exactly at mid-day when the Sun crosses the Local Meridian.

The purpose and the method of observations of this instrument are exactly the same as explained later while describing the western face of this Yantra. The idea for providing another similar instrument was, however, to compare and ascertain the observations and calculations as two observers could observe the same heavenly body at the same time.

7-II DAKṢIṆOVṚTTI BHITTI YANTRA AT DELHI : (Plate No. 25)

This small Meridinal Wall Instrument is erected on the eastern wall of the Miśra Yantra. This is the smallest instrument of its kind built by the astronomer Maharaja. It consists of a small semi-circle which is situated upside down on the wall which accurately lies in the plane of meridian of Delhi. The semi-circle is graduated in 180 degrees which are further sub-divided into minutes. There is a hole provided at the centre of the semi-circle where a peg is fixed to tie a thread for the purpose of observation.

This instrument is different in shape from its counterparts built elsewhere in the country. The method of observation is also somewhat different here as it is in the form of an inverted semi-circle. As mentioned above, a thread is tied to the peg fixed at the bottom and then the thread is stretched to the graduated arc to align it with the Sun exactly at its Meridian Pass Time which can be observed on the near by Samrāṭ Yantra. The observer has to lie down and look at the Sun with the

medium of the peg and the thread. The same process is adopted for the observation of heavenly bodies at night as they cross the meridian.

For the observation on this instrument two persons are required—one to hold and align the thread with the heavenly object and the other to observe the same from down below. The position of the thread on the graduated arc gives the altitude of the heavenly body at its Meridian Pass Time. Other calculations are done in the same manner as explained for its counterpart at the Jaipur Observatory. The graduations are done in lime and plaster which can hardly be read now.

7-III DAKṢIṆOVṚTTI BHITTI YANTRA AT UJJAIN (Plate No 26)

Eastern Face :

This Meridinal Wall or the Transit Instrument is situated in the south-western corner of the Ujjain Observatory. The Yantra consists of a well (about 22 feet high) accurately placed in the plane of the meridian circle (the circle joining north, south and the zenith points). Two quadrants each of 20 feet radius are well marked on the eastern face of this Meridinal Wall. These are distinctly graduated in degrees and their sub-divisions. The 90 degree quadrants intersect each other at an angle of 60 degrees and hence the yantra also serves as Sextant.

There are two metal pegs provided at the top of both the quadrants and strings are tied to them for the purpose of observations. When the object is to the south of the Prime Vertical, the southern peg is used and when a celestial object is north of the Prime Vertical, the northern peg is used for making celestial calculations. This happens to be the biggest of all the Meridinal Wall Instruments raised by Sawai Jai Singh in his Vedhaśālās. Like its counterparts elsewhere, this instrument is only used for observations when a heavenly body crosses the local meridian circle.

On the top of this Bhitti Yantra two minor metal instruments are also provided since 1953. One of them is in the form of an arrow which rotates on a vertical metal rod and indicates the direction of the wind. The other metal instrument placed in the north corner records the velocity of wind. Two other minor yantras having marble dials and metal gnomons placed in the southern corner on top of the Bhitti are the simple Sun-Dials as already explained.

7 - IV DAKṢIṆOVṚTTI YANTRA AT VARANASI : (Plate No. 27)

There are two similar Meridinal Wall Instruments made on two different walls in the Varanasi Observatory.

The bigger of the two Yantras, is based on the eastern wall of the Samrāṭ Yantra, which is situated in the plane of meridian. It's facing east. It consists of two quadrants of 10 feet 7 inches radius each. The quadrants intersect each other at an angle of 60 degrees. Each quadrant is graduated in 90 degrees where each degree is sub-divided in 10 parts. Two metal pegs or pointers are provided on top of each quadrant. They serve as gnomons as their shadow falls on the graduated arcs at mid-day. The inner portion of the quadrants is graduated in Devanāgarī numbers and the other one in Roman numerals at a difference of 6 degrees. 90 degrees in Roman on the other circle correspond to zero degree in Hindi engraved on the inner circle and vice-versa. The inner circle is meant for the altitude observation and the outer circle is meant for the Z. D. observations.

The smaller Meridinal Wall Instrument is based in the western corner of the observatory where small wall is erected in the plane of meridian. It is similar to its counterpart as explained above. There are also two quadrants of 7 feet 10 inches radius each. They are about 5 inches wide and intersect each other at 60 degrees. Both quadrants are graduated in 90 degrees. The inner portion bears 90 degrees marked in Hindi and the outer portion in English. This was obviously done at the time of its

restoration. The graduations on both the quadrants are spaced at 6 degrees. 90 degree mark of the inner circle correspond to zero degree on the outer one and vice-versa. The inner circle is meant for the altitude observation and the outer one for the zenith distance observation. Each degree is sub-divided in 6 parts. Two metal pegs or pointers are provided on top of each quadrant for the observation of their shadow when it falls on the graduated arcs below.

The Maharaja's idea of marking two similar Sextant instruments in the observatory was to enable two astronomers to make observations on both of these instruments simultaneously for comparing results.

7- V DAKṢIṆOVṚTTI YANTRA AT MATHURA :

The Meridinal Wall Instrument was a favourite instrument of Sawai Jai Singh which is available in his all the four existing observatories. His smallest observatory at Mathura was also adorned by a Meridinal Wall Instrument similar to its counterpart at the Jaipur Observatory. This Yantra does not exist any longer and more details about it are not available.

PURPOSE OF DAKṢIṆOVṚTTI YANTRA :

Latitude of the place Length of Day and Night, Zenith Distance, Altitude at Noon, Meridian Pass Time, Declination at Noon, Rising and Setting Time of the Sun, etc. are determined with the help of this instrument at mid-day.

Zenith Distance, Altitude, Length of Night, Declination, Rising and Setting Time of Stars and Planets, etc. are determined at their Meridian Pass Time with the help of this instrument during night.

OBSERVATION DURING DAY :

By observing the shadow of the peg that falls on the semi-circular scale every day exactly and only at local 12 0'clock, the zenith distance of Sun is determined. By the zenith distance,

the altitude of the Sun at noon is calculated. The latitude of the place is verified by calculations on this instrument. The time of Sun-rise and Sun-set is also calculated on the basis of which the Length of Day is known. The declination of Sun is also observed on the basis of which the hemispherical position and the longitude of the Sun are calculated with the help of this instrument.

ZENITH DISTANCE :

The Sun crosses the Local Meridian every day exactly at Local 12 O'clock. At this time, the shadow of the iron-peg is the longest and falls on the semi-circular scale. The reading in degrees and the fraction thereof of the shadow touching the scale is the zenith distance of the Sun on the day of observation.

ALTITUDE :

By deducting the zenith distance from 90 degrees, the altitude of the Sun is found out.

EXAMPLE :

On 3rd March, 1971, at mid-day, if the shadow falls on the semi-circular scale on 34 degrees, the zenith distance of the Sun would be 34 degrees. The altitude of the Sun, therefore, would be 90 degrees − 34 degrees = 56 degrees, on that particular day of observation.

LATITUDE :

By adding or subtracting the declination of the Sun from the zenith distance, the latitude of Jaipur (26 deg. 56 min. 27 sec. = 27 degrees) is found out every day. The south side declination is subtracted and the north side declination is added in the zenith distance to know the latitude of Jaipur.

From 21st March to 22nd September the declination of the Sun is north-wise and from 23rd September to 20th March, the declination is south-side every day. Therefore, from 21st March

to 22nd September, the zenith distance at noon is added to the declination and from 23rd September to 20th March, it is subtracted from the zenith distance to find the latitude of Jaipur every day.

EXAMPLE :

On 3rd March, 1971, the Zenith distance is 34 deg. and the declination at noon is 7 deg. south. Therefore, the latitude of Jaipur on the same day would be 34 deg. –7 deg. = 27 degrees. On 26th March, 1971 the declination of the Sun is 2 deg. North, and the zenith distance at noon, on the same day, is 25 degrees. Therfore, the latitude of Jaipur, on the day of observation, would be 25 deg. + 2 deg. = 27 degrees.

Though the latitude of Jaipur, 27 degrees, is fixed, yet this calculation is done to verify other results. After having made the calculations on the basis of the above mentioned method, if one gets 27 degrees as latitude of Jaipur, it verifies the correctness of observations and speaks of the authenticity of the instrument.

THE SUN-RISE TIME :

After knowing the latitude and declination, the Ascensional Difference is known. When the sun is in the northern hemisphere (From 21st March to 22nd September) the Ascensional Difference in minutes is deducted from 6 hours, and when the Sun is in the southern hemisphere (From 23rd September to 20th March), the Ascensional Difference in minutes is added to 6 hours to find the local time of Sun rise. Hence 6 hrs. + 15 min. 12 sec. = 6 hrs. 15 min. 12 sec. would be the Local Sun Rise Time on 3rd March, 1971.

DECLINATION :

After knowing the zenith distance by this instrument, the declination is easily arrived at by adding to or subtracting the latitude from the zenith distance.

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EXAMPLE :

On 3rd March 1971 the zenith distance is 34 degrees. By deducting 27 degrees, the latitude of Jaipur, from the zenith distance, the declination of the Sun would be (34 deg. –27 deg. =) 7 degrees at noon on the day of observation. This declination is South.

THE SUN-SET TIME :

The Local Sun-Set can be found out by deducting the Local Sun-Rise Time from 12 hours. According to the same example of 3rd March, 1971 the local Sun-Set Time would be (12 hours – 6 hours 15 minutes 12 seconds =) 5 hrs. 44 min. 48 sec.

THE LENGTH OF DAY :

The length of day is calculated by deducting the local Sun-rise time from the local Sun-set time. According to the above cited example, the length of day on 3rd March, 1971 would be (5 hrs. 45 min. –6 hrs. 15 min. =) 11 hours 30 minutes.

THE ASCENSIONAL DIFFERENCE :

The Ascensional Difference can be calculated with the help of declination and latitude by the following method.

The latitude is multiplied by declination and divided by 5 to get the Ascensional Difference.

EXAMPLE :

According to the above mentioned example of 3rd March, 1971 :

$7 \times 27 = 189 \div 5 = 38$ 'charpalas'. The 'Charpalas' are divided by 2.5 to get the minutes as 1 'Charpala' is equivalent to 24 seconds.

Thus, $\frac{38 \times 2}{5} = 15$ minutes 12 seconds. Therefore, the Ascensional Difference on 3rd March, 1971 would be 15 min. 12 sec.

THE HEMISPHERICAL POSITION OF THE SUN:

The hemispherical position of the Sun is known by the zenith distance of the Sun as observed and calculated on the semi-circular scale. When the Z. D. is more than 27 degrees, the Sun would be in the southern hemisphere and when the Z. D. is less than 27 degrees, the Sun would be in the northern hemisphere.

THE LONGITUDE OF THE SUN :

After knowing the declination of the Sun, the longitude of the Sun can be measured by certain mathematical and astronomical calculations with the help of this instrument which will need volumes to explain and elucidate.

OBSERVATION DURING NIGHT :

A star or a planet is visible from the semi-circular scale through the peg only when it comes on the meridian at a particular time. At that time of observation, the observer has to sit down on one of the steps, provided for the purpose by the quadrant, and look at the heavenly body by keeping his eye on the arc in such a way that the heavenly body falls in a straight line with his eye through the medium of the peg. The point where the eye touches the graduated arc on the wall is pin-pointed and all the calculations are done similar as explained earlier for the observations during day. To make the observation a bit easier, a thread is tied to the peg above and is stretched from above the arc. The observer moves this thread over the graduated arc while looking at the heavenly body until the thread is exactly aligned on the object under observation. The point where the thread is touching the arc is taken into account for all calculations as its reading from the upper end of the quadrant will be the altitude of the object observed.

The observations of different stars and planets and their positions are possible on this instrument during night only when the particular heavenly body crosses the Local Meridian.

The purpose and the methods of observations of this instrument are exactly the same as explained earlier while describing the western face of the Dakṣiṇodak Bhitti Yantra. The idea for providing another similar instrument, however, was to compare and ascertain the observations and calculations as two observers could observe the same heavenly body simultaneously.

8. RĀŚIVALAYA OR RĀŚI YANTRAS : The Zodiac Instruments :

This is a group of unique instruments designed and constructed by Sawai Jai Singh for his personal observatory at Jaipur. No description of this yantra is available in the ancient astronomical works. There is no evidence either to suggest that the Muslim astronomers who preceded Jai Singh used such instrument in their stone observatories. This group of curious instruments is constructed on the principle of the zenith distance of the zodiac sign and its relation with the latitude of the place. Though this principle existed before but is was translated in stone instruments by Sawai Jai Singh in the eighteenth century.

Brahmagupta's Quadrant (7th century A. D.) was employed for finding the altitude, declination, zenith distance etc. and later on the longitudes and the latitudes were determined by mathematical calculations. The ancient astronomers, thus, banked upon the mathematical formulae to calculate the astral placements. Sawai Jai Singh spearheaded the observational astronomy in India by devising the Rāśi Yantras in such a way that the longitude and the latitude of the planets could be determined directly on the graduated quadrants of these twelve zodiac instruments. These instruments are crucial from observational point of view and they augment the beauty and importance of the Jaipur Observatory to a great extent.

8 - I. RĀŚIVALAYA AT JAIPUR : (Plates No. 28 & 29)

There are 12 instruments on a large rectangular platform. They all look alike from a distance. Also each one appears to be

a miniature prototype of the Bṛhat Samrāṭ Yantra. The cluster of these instruments is known as 'Rāśivalaya'. These are 12 in number as each one of them represents one Zodiac sign like Aries, Taurus, Gemini etc.

The 'Rāśivalaya' by its unique characteristics is inimitable. It is the only instrument of its kind in the world. With its presence here, the Jaipur Observatory is placed supreme among all other such centres either built by Maharaja Sawai Jai Singh or by any other astronomer all over the globe.

The 'Rāśivalaya' came as an after-thought to the Maharaja. Though this instrument is mainly for the determination of longitude and latitude of planets, it is the only instrument which yields these results by direct observations. Some other instruments stand for giving similar results with equal exactness. But these results are reached at only through detailed mathematical calculations. The 'Rāśivalaya' needs no such mathematical exercise. Its results are available immediately at the time of direct observations.

Having set up several instruments at Jaipur Observatory, the astronomer-Maharaja felt the need of an instrument which could relieve the observer of mathematical exercises. He, therefore, built the 'Rāśivalaya' in 12 parts each standing for its own specific purpose. It is because of these qualities that this instrument has an unparalleled place in astronomy.

These 12 instruments, representing 12 signs of Zodiac are designed like the 'Samrāṭ Yantra'. Each one consists of a gnomon with quadrants on either side which are graduated in sines and degrees. The 'Rāśi Yantras' and the 'Samrāṭ Yantra', however, are different from each other. While the quadrants of the 'Samrāṭ Yantra' represent the Equator, the quadrants of the 'Rāśi Yantras' represent the Ecliptic. At the time of observation, the gnomon of the 'Rāśi Yantras' points towords the Pole of the Ecliptic, whereas the gnomon of 'Samrāṭ Yantra' always towards the North Pole.

CONSTRUCTION AND GRADUATION :

The radius of the quadrants of four of these instruments is 5 ft. 6 inch each, whereas of the remaining eight the radius is 4 ft. 1.5 inch. Likewise the gnomon of each instrument differs from each other. The quadrants are graduated in sines and degrees to read the longitude.

On the quadrants of each Zodiac instrument, the graduations start with different numbers of degrees. As the Aries Instrument is used for observations when the Starting Point of Aries (zero degree of the Zodiac circle) culminates on the Meridian, the position of the Zodiac circle on the eastern horizon is represented by graduations of degrees on the quadrants of the Aries Instrument. When the Starting Point of Taurus culminates on the Meridian, the position of the Zodiac circle on the eastern horizon is represented by graduations of degrees on the arc of the Taurus Instrument. The quadrants of the rest of the Zodiac Instruments are graduated in degrees of longitude according to the same principle. There is a difference of 180 degrees between the eastern and the western ends of all the quadrants. For the better understanding, the table of graduations of degrees on the quadrants is given below.

Zodiac signs	Degrees of longitude on quadrants	
	East	West
1. Aries	281½	101½
2. Taurus	304½	125½
3. Gemini	331½	151½
4. Cancer	0	180
5. Leo	28½	208½
6. Virgo	54½	234½
7. Libra	78½	258½
8. Scorpio	104½	284½
9. Sagittarius	134	318
10. Capricorn	180	0
11. Aguarius	223	43
12. Pisces	255½	75½

GRADUATIONS OF COSINE AND CONTANGENT ON THE GNOMONS :

Each instrument is situated at a different angle from the Pole of the Ecliptic and, therefore, the construction of their respective hypotenuses is also differently done. It is necessary to know the local latitude and the declination of the particular Zodiac sign at its Meridian Pass Time for constructions. On the basis of the above mentioned two factors and with the help of logarithm, the angular distance from the Pole and the value of the hypotenuse are found out by mathematical calculations without much difficulty.

EXAMPLE :

On the quadrants of the Aries Instrument, the graduation starts from 91 deg. 28 min. This means the position of the Zodiac circle on the eastern horizon would be 91 deg. 28 min. when the Beginning Point of Aries sign crosses the Meridian.

The declination of this part of the Zodiac, by mathematical calculations, is 22 deg. 57 min. and the latitude of Jaipur is 26 deg. 55 min. 27.4 sec. Therefore, its cosine with the help of logarithm would come to 9.9501700 and the sine of the declination (91 deg. 28 min.) with the help of logarithm comes to 9.5909856. The difference between the cosine of latitude and the sine of declination would, therefore, be the measurement of amplitude : 9.5909856 -9.9501700 = 9.6408156 is the logarithm value.

Again, the value of its quadrant by means of logarithm would be 25 deg. $56\frac{1}{4}$ min. which is the angular position of the Aries Instrument from the Pole of the Ecliptic. Thus, the value of the angle of azimuth of the gnomon of the Aries Instrument is 25 deg. $56\frac{1}{4}$ min. according to the above mentioned mathematical calculations.

Now to find out the value of the angle of altitude of the gnomon, the knowledge of amplitude, declination and the zenith distance is necessary.

EXAMPLE :

Take the Aries Instrument for an example. The value of amplitude, as already found out by logarithm, is 25 deg. $56\frac{1}{4}$ min., the declination of the Aries sign is 0 deg. 0 min. and the zenith distance is 26 deg. 55.5 min. which is found out by addition or subtraction of latitude and declination. In one direction addition and in the other subtraction is done to find out the zenith distance. From Aries to Vergo : Latitude–Declination = Zenith Distance and from Libra to Pisces : Latitude + Declination = Zenith Distance.

Now the cosine of 26 deg. $56\frac{1}{4}$ min. by means of natural logarithm is 8993025. The cotangent of zenith distance (26 deg. 55.5 min.) by natural logarithm would be $\bar{1}$.9696874. Now this cotangent is multiplied by radius and then by dividing it by natural cotangent 8993025, to get 2.192. Its arc by logarithm would be 24 deg. 32 min. and this will be the value of the angle of altitude of the hypotenuse (cotangent) of the Aries Instrument.

The mathematical background of the construction of the Aries Instrument has been explained above. The angles of the remaining eleven instruments can be measured accordingly and their basis of construction can be known.

The gnomons have the scales of tangents to read degrees of latitude, north or south of the ecliptic. There are graduations of degrees on each gnomon, 60 degrees both north and south of the ecliptic which is represented by zero graduation on the gnomon. This means that the celestial positions of the planets can be observed on these instruments when they are 30 degrees above the horizon.

The values of the angles of azimuth and altitude of all the Zodiac instruments can be derived with the help of logarithm as explained above. A table of the angles of these instruments is given below. The angular similarity of some of the Zodiac instruments is due to their equal distance, in north or south, from the

No.	Name of signs	Longitude of signs (Degrees)	Azimuth of Gnomons (Deg. Min)	Altitude of Gnomons Deg. Min.	Sidereal Mean Time of culmination (H. M. S.)
1.	Aries	0	$-25.56\frac{1}{4}$	24.32	0 . 0 . 0
2.	Taurus	30	–21.17	14.25	1 .51 . 38
3.	Gemini	60	–12.19	$6.36\frac{1}{2}$	3 .51 . 16
4.	Cancer	90	0.0	3.39	6 . 0 . 0
5.	Leo	120	12.19	$6.36\frac{1}{2}$	8 . 8 . 44
6.	Virgo	150	21.17	14.25	10 . 8 . 22
7.	Libra	180	$25.56\frac{1}{4}$	24.32	12 . 0 . 0
8.	Scorpio	210	25.37	35.33	13 .51 . 38
9.	Sagittarius	240	17.40	45.42	15 .51 . 16
10.	Capricorn	270	0.0	50.22	18 . 0 . 0
11.	Aquarins	300	–17.40	45.42	20 . 8 . 44
12.	Pisces	330	–25.37	35.33	22 . 8 . 22

Celestial Equator. No description is however available about these angular calculations and constructions of the 'Rāśivalaya' in certain books which were attempted on the subject in the past by Mr. Garrett, Mr. Kaye and Mr. Soonawala. These mathematical and logarithmical calculations were nearly extinct. Serious efforts have been made by Pandit Kalyan Datt Sharma, the former Supervisor, Jaipur Observatory and I to unearth this process and bring it to lightfor the benefit of the readers and to satiate the curiosity of the visitors.

PURPOSE :

The purpose of the 'Rāśivalaya' or the twelve Zodiac instruments is the direct determination of the celestial longitude and latitude of planets—during day and night.

Hence these instruments form the main-base for testing the correctness of Hindu calendars and almanacs. The tables of longitude and latitude of planets are given in the almanacs, prepared on the basis of mathematical calculations. Their authenticit y is verified with the help of these instruments at any time during day and night.

OBSERVATION DURING DAY AND NIGHT :

The Zodiac Circle (Ecliptic Circle) is divided in 360 degrees. The same is divided into 12 'Rāśis' or 12 Zodiac signs which are situated at a distance of 30 degrees from each other. The Ecliptic is a circle of 23 degrees 27 minutes radius around the Pole. Henee the Pole of the Ecliptic is not a fixed point. Therefore, 12 instruments were made available for observations at 12 different times during twenty four hours. In other words, each instruments is used for approximately two minutes after every two hours. The exact interval of the culmination of each sign on the meridian is given in a table in this chapter. That means at only one particular time when a particular zodiac sign culminates on the local meridian, observations can be made for a minute or two with one particular instrument.

Therefore, for observations on these twelve Zodiac instruments, viz., Aries, Taurus, Gemini etc., the knowledge of the Meridian Pass Time of the Beginning Point of each Zodiac sign is very essential. When the Starting Point of a particular Zodiac sign culminates on the Meridian, the observations are done on that particular Zediac instrument. In other words, at a particular time a particular instrument is used for observing longitude and latitude. Therefore, the foremost duty of an observer is to know the appropriate time for the use of a particular Zodiac instrument.

For determining the longitude and latitude of planets, the observer sits by the side of the quadrant. Steps are provided for

this purpose. The observer, then, looks at the planet under study by keeping the eye on the edge of the quadrant in such a way that the eye and the planet fall in a straight line through the edge of the hypotenuse. To make the correct observation sometimes a pointer is held on the edge of the hypotenuse in such a way that it falls on the same straight line of eye and the planet. Sometimes a long metal tube is also used for the same purpose with one end on the quadrant to look through and the other touching the hypotenuse from where the planet is clearly visible through the tube.

The position of the eye on the quadrant will give the reading of the longitude in degrees and the other point on the hypotenuse will give the reading of the latitude of the planet observed.

LATITUDE AND LONGITUDE OF THE SUN :

As the Sun is always in the Ecliptic, its latitude is zero. The longitude of the Sun can, however, be found by observing on the 'Rāśivalaya'.

At the particular time of observation, the quadrants of the 'Rāsi Yantras' lie in the plane of the Ecliptic or in a plane passing through the Sun. In this case, a rod or stick (pointer) is placed perpendicular on the gnomon on 'zero' graduation and its shadow is observed on the quadrant down below. The shadow of the gnomon on the quadrant will give the longitude of the Sun in degrees at the time of observation—its latitude being always zero. This observation is done on the particular Zodiac instrument whose sign culminates on the Local Meridian at the time of observation. The names of all Zodiac signs are inscriled in their respective Zodiac circles in the nearby 'Jai Prakāśa Yantra', where the shadow of the Sun is observed to determine the particular Zodiac instrument for the purpose of observation of Sun's longitude.

DETERMINATION OF CORRECT TIME OF OBSERVATIONS :

For the correct measurement of longitudes and latitudes with the help of these instruments it is very important to know the correct time at the time of observations. Therefore, first of all, the correct time of observation for the particular instrument is found out by mathematical calculations and then the same is verified on the Bṛhat Samrāṭ Yantra. The observations are done accordingly.

How the correct time of observation for each Zodiac instrument is found out by mathematical calculations is explained below.

The Beginning Point of each Zodiac sign is 0, 31, 61, 91, 121........degrees. So for the observation on the Aries Instrument, the Meridian Pass Time of the Zero degree of the Zodiac Circle; for the observation on the Taurus Instrument the Meridian Pass Time of 31 degree of the Zodiac Circle and for the observation on the Gemini Instrument, the Meridian Pass Time of 61 degrees of the Zodiac Circle and similarly the Meridian Pass Time of the Starting Point of each Zodiac sign is necessarily found out.

There are more than one method for finding the Meridian Pass Time of the Starting Point of different Zodiac signs. But the best method for finding this time of observation is calculated by the Side Real Time.

EXAMPLE :

Suppose the observation is done on 24th March, 1972 on the Aries Instrument. So the Side Real Time in hours, as given in Indian Ephemeris, is O hrs. 7 min. 19 sec. By adding 4 seconds to it (which is done to correct the Side Real Time for Jaipur) the Side Real Time of Jaipur will be O hrs. 7 min. 23 sec. That means that the zero degree of the Zodiac circle had come on the Meridian 7 min. 23 sec. before mid-day. Now this Side Real

Time is converted into Terrestrial Time for which a difference of 10 seconds in one hours is taken into account. So in 7 min. 23 sec. this difference will be of about 1 second. Therefore the Beginning Point of the Aries sign came on the Meridian 7 min. 22 sec. before mid-day. In other words it came on the Meridian at 11 hrs. 52 min. 38 sec. Local Mean Time. Then this L. M. T. is converted into I. S. T. for which the Mean Difference of Jaipur (26 min. 48 sec.) is added to it to get (11 hrs. 52 min. 38 sec. + 26 min. 48 sec. =)12 hrs. 19 min. 26 sec. I. S. T.

This means on 24th March, 1972, the Aries Instrument would be used for observations of Sun's longitude and latitude at 12 hrs. 19 min. 26 sec. Similarly the time of observation on each instrument can be known by mathematical calculations every day and the instruments can be used accordingly. The simplest method would be to find out the Meridian Pass Time of the Starting Point of Aries sign and then add to it the duration (in hours, minutes and seconds) of each Zodiac sign remaining on the Meridian to know the appropriate time of observations on each Zodiac instrument.

The duration of each Zodiac sign remaining on the Meridian about two hours–is always stable and invariable which is given in the table below. The Meridian Pass Time of the Beginning Point of the Aries sign changes by minus 3 min. 56 sec. everyday–though the duration of its remaining on the Meridian is always the same.

In the table below, the appropriate time of observation on each Zodiac instrument for 24th March, 1972 is given, the day when the Aries instrument can be used at 12 hrs. 19 min. 26 sec. as explained above.

No.	Zodiac Sign	M. P. T. H. M. S.	Duration of Terrestrial time on Meridian (H. M. S.)	Time for culmination of next sign on meridian (H. M. S.)
1.	Aries	12.19.26	1.51.17	2.10.43 P. M.
2.	Taurus	2.10.43	1.59.16	4. 9.59 P. M.
3.	Gemini	4. 9.59	2. 8.27	6.18.26 P. M.
4.	Cancer	6.18.26	2. 8.27	8.26.53 P. M.
5.	Leo	8.26.53	1.59.16	10.26. 9 P. M.
6.	Virgo	10.26.9	1.51.17	12.17.26 A. M.
7.	Libra	12.17.26	1.51.17	2. 8.43 A. M.
8.	Scorpio	2.8.43	1.59.16	4. 7.59 A. M.
9.	Sagittarius	4.7.59	2. 8.27	6.16.26 A. M.
10.	Capricorn	6.16.26	2. 8.27	8.24.53 A. M.
11.	Aquarius	8.24.53	1.59.16	10.24. 9 A. M.
12.	Pisces	10.24.9	1.51.17	12.15.26 P. M.

Thus by knowing the observation time for the Aries Instrument, the appropriate time of observation for other eleven Zodiac instruments can be known by adding the invariable duration (in hours, minutes and seconds) of each sign remaining on the Meridian as given in the table above. It may be noted that the time of celestial observation on each Yantra is only for about two minutes when each Zodiac sign crosses the meridian. Only expert astronomers can, therefore, utilise these complicated Yantras.

The Local Time can be easily observed by the shadow of the gnomon on the giant quadrant of the Bṛhat Samrāṭ Yantra during day. Then the Local Time can be converted into the Indian Standard Time for the purpose of observation on a particular instrument. The same is observed during night with the help of certain prominent stars by knowing their Meridian Pass Time and their position at the time of observation. This Time is always I. S. T. The method of observing Time during night has

been described in detail while narrating the function of the Samrāṭ Yantra (No. 1).

The reading of celestial latitude and longitude is in tropical sine or with 'ayanāṃśa' (precession) and so the observer has to deduct the 'ayanāṁśa' (precession) from the tropical reading in order to get the reading in 'niryan' (without precession) according to the Indian system.

9. JAI PRAKĀŚA YANTRA : The Armillary Sphere Instrument :

In the ancient astronomical texts there are references about the instrument which represents the celestial sphere. Varāhamihira described such an instrument in his 'Pañca Siddhāntikā' and Bhāskarācārya mentioned a similar instrument in his 'Siddhānta Śiromaṇi'. The instrument was made of either wood or metal in a spherical form and different bands representing various astronomical circles were stretched across and tied. It was made in small proportions. Such an instrument representing the celestial globe was used for demonstration purpose to explain the theoretical and practical aspects of astronomy. This Yantra was not extensively used for actual observations in ancient times.

The 'Sūrya Siddhānta' gives elaborate instructions for making a sophisticated Armillary Sphere : "Let the teacher for the instruction of the pupil prepare the wonder working fabric of the terrestrial and steller sphere. Having fashioned an earth-globe of wood of the desired size, fix a staff passing through the midst of it and protruding at either side for Meru and likewise, a couple of sustaining bands and the equinoctial circle. These are to be made with graduated divisions of degrees of the circle. Further, by means of a several day-radii as adopted to the scale established for those other circles and by means of the degrees of of declination and latitude marked off upon the latter, at their own respective distances in declination according to the declin-

ation of Aries etc. Three bands are to be prepared and fastened. These answer also universally for Capricorn etc. and situated in the southern hemisphere are to be made and fastened to two band supporters. Those likewise of the asterisms situated in the southern and northern hemispheres of Abhijit (Lyrae), of the Seven Sages of Agastya and Brahmā are to be fixed. Just in the midst of all, the equinoctial band is fixed above the point of intersection of that, are two solstices and two equinoxes. Oblique chords for the spaces of Aries and the rest. Band running from solstice to solstice is called the circle of declination upto which the sun revolves."

Sawai Jai Singh decided to make an Armillary sphere not for the demonstration purpose but for making the actual observations. So he chose to make it on a much larger scale. He is accredited as the designer of this Yantra as he made it in a cavity turning the celestial sphere up side down. This inverted hemisphere was graduated in detail. Another novel idea of Jai Singh was to capture the shadow of the sun by providing a metal ring at the centre of the Yantra, held by a cross-section of wires. The same ring is used for observing the astral bodies from down below at night. Sawai Jai Singh's original thinking is also reflected it graduating the scales to get the tenth house of the Zodiac signs instantly, without any calculations. This was very significant from astrological point of view. The idea of making two complementary instruments to facilitate the observations at any time during day or night was also his own. This instrument is named after the royal astronomer as 'Jai Prakāśa' or the 'Light of Jai' as Sawai Jai Singh exhibited his genius in designing and constructing this incredible instrument.

9 - I JAI PRAKĀŚA YANTRAS AT JAIPUR : (Plates No. 30 to 34)

This instrument is situated between the 'Nārivalaya' (No. 3) and the 'Rāśivalaya' (No. 9) instruments. It is in the concave shape of a hemispherical bowl which is sunk into the earth. The huge hemispherical bowl represents the visible heaven

which is turned upside down as the rim of the instrument represents the horizon. This instrument was so created by Maharaja Sawai Jai Singh that it provided far more accurate calculations which had seemingly a minor ratio of inaccuracy in observations made at other metal instruments which were much smaller in size than this huge spectacular bowl of marble slabs and sand stone.

The diameter of this instrument is 17 feet 10 inches. A cross-section of metal wires is fixed over the rim indicating north-south and east-west. A small metal ring exactly over the centre of the instrument is fixed to wires. The rim, representing the horizon of Jaipur, is graduated in 360 degrees which are further sub-divided into 10 parts each. The altitude circles, numbering 15, at a difference of 6 degrees each, are drawn parallel to the horizon over the curved scales of the instrument. 27 degrees below the horizon, the Pole Star is depicted on the southern portion of the instrument. Around this point, the ecliptic circle is also drawn which is inscribed as Kadamba-Bhrīma Vṛtta in Sanskrit. Joining exact north and south points of the rim is the meridian circle. At a distance of 90 degrees from the point of the Pole Star, another thick line joining the east and west points on the rim, is drawn which represents the celestial equator. From the celestial equator, at the difference of their declination, twelve lines from Aries to Libra, representing twelve different positions of the zodiac, one for each rising sign, are also drawn criss-crossing the marble scales. As a matter of fact, 12 signs of zodiac are represented by 6 lines drawn on both sides of the equator which can be easily identified by their respective zodiac names which are inscribed in white marble with lead in each zodiac circle.

There are two identical Jai Prakāśa instruments which exist side by side. Both are used for the same purpose. Both are complimentary to each other. The space left between the marble scales for the purpose of observations and calculations

in one instrument is filled by the marble scales in the other and vice-versa. Thus, these two instruments function on alternate hours and can be used round the clock. Each curved marble scale stands for hour long observations.

9 - II JAI PRAKĀŚA YANTRAS AT DELHI : (Plate No. 35)

This Hemispherical Instrument is situated south of the Samrāṭ Yantra. It consists of two hemispheres, each of 27 feet 6 inches diameter, which are concave in shape and sunk in the raised platforms. These bowl shaped instruments represent the interior hemisphere of the visible heavens. The celestial sphere is turned upside down as the rim of the instrument represents the horizon divided into 360 degrees. Both the instruments are complimentary to each other as the sectors in one correspond to the space in the other which is done to make any part of the instrument accessible for observations during day and night.

Originally there were two wires stretched over the rim indicating East-West and North-South. The inter-section of these wires held a metal ring exactly over the centre of the instrument. The hooks where these wires were fastened are still there though there is no trace of wires and the metal ring. Later on, a post was fixed at the centre of the instrument where a big hole provided for this purpose can still be seen though the post has been removed.

The shadow of the metal ring or the central post was observed on the graduated surface of the instrument for determining the position of the Sun.

There are six sectors in each instrument which had the circles of altitude, azimuth, declination, meridian, equator, tropics and the signs of the Zodiac engraved on the surface of the instrument in lime and plaster which have now completely disappeared. No observation can be made on this instrument as it is in a dilapidated condition.

The Equinoctial Observation :

The Jai Prakāśa Yantra at the Delhi Observatory has a unique feature. There is a hole made in the southern wall of the instrument for the purpose of observation of the Sun's equinoctial position. The surface having this hole is made inclined by 28 degrees 39 minutes, equivalent to the latitude of Delhi, so that the rays of the Sun enter into the small chamber below as soon as the Sun touches the equinoctial point. This happens only twice in a year, viz., on 21st March and 23rd September when the Sun comes on the equator which results in the equal duration of day and night.

PURPOSE OF JAI PRAKĀŚA YANTRA :

Local Time, Altitude, Azimuth, Meridian Pass Time, Zenith Distance, Declination of Stars and Planets, Longitude of Planets the Starting Time of per 10th House of the Zodiac etc. are determined with the help of these instruments both during day and night.

OBSERVATION DURING DAY : LOCAL TIME :

The Local Time is observed by the shadow of the metal ring that falls on the marble scale below. At local 12 O'clock, this shadow invariably falls on the Meridian Circle every day. Thus, before Local 12 O'clock, this shadow falls on the west of this circle and after Local 12 O'clock, east of this circle. The marble scales and the space in between them represent one hour each in both instruments. If in the northern instrument, the shadow of the metal ring falls on the first scale, east of the meridian circle after the first gap, this would mean that the time is between 1 and 2 O'clock. In order to know exactly the minutes after 1 O'clock, the scale that represents 60 minutes by its breadth is measured and its proportion is taken into account to find the Local Time in hours and minutes.

To find the I. S. T. on the basis of Local Time, the differance of time is added to Local Time. A table of difference of time for this conversion is given elsewhere in the book.

ALTITUDE :

As already mentioned, 15 altitude circles at a difference of 6 degrees each are drawn parallel to the horizon in this instrument to observe the altitude. If the shadow of the metal ring falls on the third circle, it would mean that the altitude of the Sun at that moment is $3 \times 6 = 18$ degrees. If the shadow falls in the middle of the 3rd and 4th circle, the altitude would be 21 degrees as the ratio of the shadow spot on a part of the altitude circle is counted on the basis of 6 degrees which represent the space in between any two altitude circles. The cross-wires must be well fastened at the time of observation for correct reading. Before noon, the altitude of the Sun is considered from the eastern horizon and in the afternoon, from the western horizon.

AZIMUTH :

To determine the azimuth of the Sun, a perpendicular rod is held on the centre of the shadow of the ring. Then a thread is tied in the metal ring and stretched upto horizontal rim touching the rod. The point where the thread touches the horizon is counted from the southern most point of the horizon to arrive at the azimuth of the Sun.

MERIDIAN PASS TIME :

At Local 12 0'clock, the Sun crosses the Meridian every day. At the time of observation the distance of the cross-wire shadow from the meridian circle is measured to find the Meridian Pass time. If the shadow is falling 2 hours west of the meridian circle, the Sun would pass the meridian after 2 hours. If the shadow is falling 4 hours east of the meridian circle, it indicates that the Sun has passed the Meridian before 4 hours. As already mentioned, each marble scale and the space in between them

represents one hour. So if the shadow falls somewhere in between the scale, its correct time can be observed by measuring its place on the scale representing 60 minutes, by calculations.

DECLINATION :

Exactly at mid-day, the cross-wire shadow falls on the meridian circle which is graduated in 90 degrees of 6 minutes each. Where the cross-wire shadow touches the part of the Meridian, the degrees and minutes are counted from the Equator to determine the declination at noon. Before or after mid-day this shadow is visible on either east or west of the Meridian Circle. From this shadow spot a straight line is drawn upto the Meridian Circle making an angle of 90 degrees on it. A thread can also be used for the same purpose. This point is measured from the Equator to know the declination of the Sun.

LONGITUDE OF PLANETS :

There is Celestial Equator drawn in this instrument from where at the difference of declination, Aries to Pisces, 6 Zodiac circles are drawn on its both sides. During day, if the cross-wire shadow falls on the Aries circle, it means the Sun is on the Aries sign. When the shadow falls on Taurus circle, it indicates that the Sun enters into Taurus. On 21st March and 23rd September, the cross-wire shadow falls on the Equator. On 21st March the Sun enters Aries sign and on 23rd September it enters into Libra sign. From 21st March to 22nd June, the shadow moves northward from the Equator. On 22nd December the Sun enters into Capricorn. This way the Sun goes on passing through all the 12 signs of the Zodiac.

The angular distance of the planet from the vernal equinox is known as its longitude, which is measured with the help of this instrument.

As the difference between any two Zodiac circles is of 30 degrees, the position of the shadow spot is observed in any Zodiac

circle and the longitude of the Sun is measured by the rule of three.

THE BEGINNING TIME OF 10TH HOUSE :

There are 12 circles of 10th House which are 12 part of 30 degrees each of the Zodiac. They are demarcated here by curved lines and the names of different Zodiac signs are inscribed. The 10th House is that point of the Zodiac circle which touches the Local Meridian circle. This could be observed here. When the cross-wire shadow touches the first circle (Aries) it means the Beginning Time of the Aries 10th House. When the shadow touches the second circle (Taurus), it indicates the Beginning Time of the Taurus 10th House and so on.

If the shadow falls in between two circles, the degrees are counted by measurement as the difference between the two circles is of 30 degrees.

There are 12 other instruments known as the 'Rāśivalaya' for finding the longitude and the latitude of planet. They are known after each sign of the Zodiac. Each smaller instrument helps in the exact study of the longitudes and latitudes of the planets after the initial study is made at the Jai Prakāsa Yantra. A detailed account about it appears for 'Rāśivalaya' (No. 3).

OBSERVATION DURING NIGHT :

For observations at night there is no shadow of the cross-wire ring falling on the scales. Therefore, the observer has to go down at the bottom of the instrument and observe the particular heavenly body under study by positioning himself by one of the marble scales. The observer then gazes at the heavenly body in such a way that his eye, the hole of the metal ring and the planet or star fall in a straight line. In this process the observer has sometimes to lie down keeping his head on the marble scale. The position of the eye on the scale is pinpointed on the scale for calculations to be done in the manner already described.

10. KAPĀLI YANTRA : The Hemispherical (Bowl) Instrument :

Kapāla or Kapāli Yantras were described and utilised by ancient Hindu astronomers like Varāhamihira, Brahmagupta and Bhāskarācārya. The Kapāla was made in the shape of a hemispherical bowl of metal with a hole at its bottom. It was later filled with sand or water. This Yantra was generally used as a Sand or Water-Clock to determine time. Sawai Jai Singh made this hemispherical bowl of the ancients in marble with much more sophistication. He graduated the entire inner surface by various astronomical circles making it a 'Celestial Bowl' for elaborate observations.

This is a small version of the Jai Prakāśa Yantra (the Armillary sphere) described earlier. This yantra is a combination of Unnataṃśa (altitude) Digaṁśa (azimuth), Yamyottara (Celestial equator) and Palabha (Sun-Dial) Yantras. A composite form of various Yantras was, thus, devised by Sawai Jai Singh. This is the only instrument of its kind which adorns the Jaipur Observatory.

10-I KAPĀLI YANTRA AT JAIPUR : (Plate No. 36)

The Kapāli Yantra is made of white marble slabs forming the shape of a large bowl sunk into the ground with its rim touching the level of the surface. A very look at the instrument is somewhat pleasing as the entire surface of the bowl is criss-crossed by numerous lines, all of them forming semi-circles within the instrument. Scores of lines run into one another in such a way that the instrument seems to a visitor as a labyrinth of lines.

The rim of the instrument represents the horizon and is graduated into 360 degrees which are clearly visible engraved in lead. Down the rim, there are 15 circles drawn parallel to the horizon, each at a difference of 6 degrees. They are known as altitude circles.

The instrument is divided into two equal segments by a prominent line running north-south. This line represents the

Meridian Circle, passing through the centre of the instrument. As against the lines parallel to the rim of the instrument (the horizon), there are lines drawn parallel to the Meridian Circle on both the east and the west sides. These are drawn at a difference of 24 minutes and, thus, are 30 in all.

Another prominent line passes from east to west in the instrument. This represents the Celestial Equator which is drawn 27 degrees north of the vertical circle. The Equator Circle and six circles drawn parallel to it stand for different Zodiac signs. The Equator Circle stands for the Zodiac signs of Aries and Libra. In the north of the Equator, three circles are drawn representing Scorpio-Pisces, Sagittarius-Aquarius and Capricorn signs respectively. In the south of the equator three more Zodiac circles are drawn which represent Taurus, Virgo, Gemini, Leo and Cancer signs respectively. All the size Zodiac circles are drawn at the difference of their declination and they can be easily distinguished from one another as their names are inlaid in their respective circles. Aries to Pisces, Ascendant circles are also drawn in this instrument.

The Pole Star is depicted 27 degrees below the horizon on the southern part of Kapāli. The Ecliptic circle of 23 deg. 27 min. radius is also drawn around the Pole which is inscribed as 'Kadamba-Bhrīma Vṛttam' in Sanskrit.

Two wires are fastened over the rim crossing each other exactly above the centre of the instrument. A metal ring is fixed at the inter section of wires. The shadow of the ring falls on the instrument down below and it is of vital use at the time of observations and calculations.

PURPOSE :

The Local Time, the Meridian Pass Time, the Azimuth, the Longitude of Planets and the Tropical Ascendant of Planets and Stars, during day and night are observed with the help of this instrument.

OBSERVATION DURING DAY : THE LOCAL TIME :

Circles parallel to the Meridian are used for finding out the Local Time. During day, if the shadow of the ring falls on the first circle, west of the Meridian Circle, it would mean that the Sun would come on the Local Meridian after 24 minutes. Hence the Local Time is 11 hrs. 36 min. If the shadow falls on the second circle, in the west of the meridian, it would mean that the Sun would come on the Local Meridian after 24+24 = 48 min. Hence the Local Time at that moment would be 11 hrs. 12 minutes. Similarly if the shadow falls on the first circle, east of the Meridian, the Local Time would be 12 hrs. 24 min. and if it is on the second circle which is in the east of the Meridian, the Time would be 12 hrs. 48 min.

If the shadow falls somewhere in between the two circles, its position is measured with a scale. It's always the centre of the shadow of the ring which is taken into account for the purpose of measurement. As the distance between two circles represents 24 minutes, the position of the shadow in between them will be measured in the same proportion. By adding the True Difference of Time, which is available in the log books, the Local Time of Jaipur can easily be converted into Indian Standard Time.

THE MERIDIAN-PASS-TIME :

On the basis of the Local Time, which is observed by the above given method, the Meridian Pass Time of the Sun is also known by this instrument.

EXAMPLE :

If the shadow of the ring falls on the first circle, west of the Meridian, the Sun would pass the Meridian after 24 minutes. If the shadow is spotted on the first circle, east of the Meridian, the Sun has passed the Meridian before 24 minutes and so on.

ALTITUDE :

As already mentioned, the altitude circles are drawn parallel to the horizontal rim of the instrument at a difference of 6 degrees each. From the horizon, these circles are counted upto the shadow spot and then their number is multiplied by 6 degrees in order to find out the altitude of the Sun.

EXAMPLE :

If the shadow is falling on the third circle from the horizon, the altitude of the Sun would be 3×6 deg. $= 18$ degrees and if the shadow falls on the fifth circle, the altitude of the Sun would be 5×6 deg. $= 30$ degrees from the horizon.

ALTIUDE FROM EAST AND WEST HORIZON :

Before mid-day, the shadow of the ring is visible on the western segment of the instrument and in the afternoon the shadow is visible on the eastern segment of the 'Kapāli'. The altitude observed before mid-day is from the eastern horizon and the same when observed after mid-day is from the western horizon for the purpose of calculations.

AZIMUTH :

To find out the azimuth of the Sun, a perpendicular rod, long enough to come higher than the horizontal level, is held at the place where the shadow falls. A thread is tied to the ring and is stretched upto the horizontal rim of the instrument in such a way that it touches the rod. Its reading from the southern-most point of the horizon is taken to know the azimuth of the Sun.

LONGITUDE OF PLANETS :

The Zodiac Circle of 360 degrees is divided in 12 equal parts of 30 degrees each. Each part stands for one sign of Zodiac, such as Aries, Taurus, Gemini, Cancer etc. Each sign is at a difference of 30 degrees from one another. The Starting Point of Aries is zero degree and the starting point of Taurus is 31 degrees and so on.

The shadow of the ring touches the Aquarius circle only on 20th January. On 19th February, it comes on the Pisces circle and on 20th March it comes on the Aries circle. On 20th April, it touches the Taurus circle, on 21st May the Gemini circle, on 22nd June the Cancer and on 23rd July it touches the Leo circle. On 23rd August it comes on the Virgo circle, on 23rd September on the Libra, on 23rd October on the Scorpio, on 22nd November on the Sagittarius and on 22nd December the shadow comes on the Capricorn circle according to the difference of their declination.

According to these dates, the longitude of the Sun is measured by spotting the shadow in between these Zodiac circles and making calculations accordingly as the difference between any two Zodiac circles is of 30 degrees.

TROPICAL ASCENDANT :

The rising time on the horizon of each sign of Zodiac (Aries, Taurus, Gemini etc.) is known as the Beginning Time of the Tropical Ascendant.

When the shadow touches the Aries ascendant circle, it means that this is the beginning time of Aries and when it touches the Taurus ascendant circle, it is the beginning time of Taurus sign and so on. If the shadow is visible in between two circles it means that the first circle has passed and the second circle will start after some time. There is a difference of 30 degrees between any two circles so the degrees can also be found out by calculations.

Suppose the cross wire shadow is falling exactly between the Aries and the Taurus ascendant circles, it would mean that the Sun has crossed 15 degrees in the Aries sign and if the cross wire shadow is visible at 3/4 of the same circle, it indicates that the Sun has passed 22 degrees of the Aries sign.

OBSERVATION DURING NIGHT :

Altitude, Azimuth, Ascendant, Meridian Pass Time, Hemispherical Position, Declination of Stars and Planets, the Longitude

of Planets, the Local Time etc. are observed with the help of this instrument during night as well.

The method of observation and measurement is the same as already explained. As the shadow of the ring is not visible at night, the observer has to lie down inside the instrument to see the particular planet or the star through the hole of the ring. In this process the eye, the hole of the ring and the particular heavenly body, all three fall in one straight line. The point from where the observer is watching the heavenly body is marked on the surface of the instrument and all above observations are done by similar calculations.

The Jai Prakāśa Yantra (No.9) and the Kapāli Yantra are almost identical in observations but the Jai Prakāśa Yantra is used to find the Beginning Time of the 10th House of the Zodiac signs whereas the Kapāli Yantra is used for finding the Tropical Ascendant of Zodiac signs.

EASTERN KAPĀLI YANTRA :

There is another bowl shaped instrument sunk into the ground which looks quite identical to the Kapāli Yantra. This is also a representation of half celestial sphere. But it is somewhat different from the Kapāli Yantra. Its rim represents the solstitial colour whereas the rim of the former represents the horizon. The lines on the surface of the instrument are also criss-crossed differently.

This instrument is not meant for any celestial observations but simply meant for solving the astronomical problems graphically.

11. CAKRA YANTRA : The Circular Instrument :

This is an improvised version of the ancient Gola Yantra or the Cakra Yantra of the Hindus. It is a meridian circle that revolves. Bhāskarācārya II described a wooden or metal instrument in the form of a circle whose circumference was graduated into 360 degrees. It had a hole at the centre where a hollow

tube was attached for the purpose of observations. It was suspended with the help of a chain and, thus, it could be rotated whenever so required. It was utilised to know the altitude and declination by placing it in different planes.

This is a metal instrument in the form of a circles which is fixed between two stone pillars. The circle is free to rotate in the plane of meridian. The circle is joined by a flat metal rod with a hole at its centre where a sighter is fixed for the purpose of observation. The metal circle is graduated in 360 degrees on which the position of the sighter is read while making the observations of the astral objects through the sighter during day and night.

11 - I CAKRA YANTRA AT JAIPUR (Plate No. 37)

There are two Cakra Yantras neighbouring each other here. Each has a circle made of 'Saptadhātu' or seven metals viz., gold, silver, iron, copper, lead, brass and zinc. The diameter of the instrument is six feet. The shape, size and working of each one are exactly the same. Both are identical.

Each Yantra is graduated in 360 degrees. A flat metal piece forms the diameter which bears a hole at its centre.

A circular metal disc is fixed on stone in the south of each of these instruments. This has the meridian line as also the markings of 'ghaṭikās' graduated on it. This disc is divided into four equal segments of 90 degrees each. Each of these four parts is divided in 15 'ghaṭikās' making it equal to six hours as one 'ghaṭikā' is equal to 24 minutes.

These days the instruments are chained and locked to stop wasteful rotation of the Circles. As the entire observatory is a fancied complex many a visitor give twist to such instruments. The chain and lock are removed whenever astronomers take us ot these instruments.

11 - II CAKRA YANTRA AT VARANASI (Plate No. 38)

The Cakra Yantra or the Declination Instrument is available at the Varanasi Observatory also. Unlike Jaipur Observatory, there is only one circular instrument here. It consists of a metal circle which is about $1\frac{1}{2}$ inches thick and 2 inches broad. The diameter of the instrument is 3 feet 6 inches. It is fixed in between two pillars and can be rotated on its axis for the purpose of observations. A hole is provided at the centre of the circle where a sighter is fixed for astronomical observations. The circle is graduated in 360 degrees, each of 4 fractions.

PURPOSE OF CAKRA YANTRA :

This instrument is used to find the declination of stars and planets and their distance in time (hour angles) from the local meridian, during day and night.

OBSERVATION DURING DAY AND NIGHT DECLINATION :

A metal tube (a sighter), available at the Jaipur Observatory office, is attached to the hole of the instrument at its centre in order to observe planets and stars. First of all, the circle is moved and adjusted to face the particular planet or star under observation. In this position, facing the Sun, this instrument should make its shadow in the form of a straight line. It is held there. Then the metal tube, already attached at the centre, is slowly moved on the metal circle in order to see the particular heavenly body through it. When the planet or the star under observation is clearly visible through the tube, the tube is held at that point and its position on the graduated circle is read in degrees to measure the declination of the planet or the star during day and night.

The declination is observed both north and south. At the time of observation if the upper end of the tube is in north of the diameter, the declination measured would be North of the Celestial Equator and when the upper end of the tube is in south

of the diameter, the declination measured would be South of the Celestial Equator.

MERIDIAN PASS TIME :

A small hole can be seen on the southern axis of the circular instrument where a long nail is struck in at the time of observation. When a planet or a star under study, is visible through the tube, as explained above, the reading of the nail is taken on the small disc in 'ghaṭikās' which can be converted into hours and minutes.

Before the Meridian Pass Time of the particular heavenly body, one should observe standing in the west of the instrument while after the Meridian Pass Time, one should observe it standing in the east of the instrument.

By observations made on the main circle the declination and also the Meridian Pass Time are measured. But through the small disc, one can find out as to when the particular heavenly body will pass the Meridian and before what time it has already passed the Meridian. The reading is taken in 'ghaṭikās' which are converted into hours and minutes as one 'ghaṭikā' is equal to twenty four minutes. Hour angle is the distance in time from the meridian which is determined on this instrument. As the astronomer-Maharaja preferred stone instruments to metal ones, he erected another giant instrument viz., the Samrāṭ Yantra which is also used for measuring the declination and the Meridian Pass Time of the astral bodies in a more simple and accurate way.

12. RĀMA YANTRA : The Altitude/Azimuth Instrument :

The ancient Indian astronomers used the Unnataṃśa Yantra in the form of a suspending circle to determine altitude of heavenly bodies as described earlier. They also used a Yaṣṭi (gnomon) whose shadow was observed on a graduated dial made in the plane of horizon. No description is, however, available in the ancient texts of an instrument like the Rāma Yantra. This sophis-

ticated Altitude Instrument was designed by Sawai Jai Singh. He gave it an entirely new shape by making the horizon towards the sky and turning the sky up side down. Contrary to the earlier practice, the gnomon's shadow is observed on the graduated cylindrical scales representing the inverted celestial sphere. Another novel idea of Sawai Jai Singh is reflected in making two complimentary instruments functioning alternately. This was done to make every inch of the instrument accessible to facilitate observations. The Yantra is named after Maharaja Ram Singh, one of the ancestors of Sawai Jai Singh.

12-A RĀMA YANTRA AT JAIPUR (Plates No. 39 to 41)

Two identical looking instruments stand in the southern corner of the observatory. In shape and functioning they look similar but a minute difference between the two reveals the significance of each one.

A high cylindrical wall (11 feet 4 inches) forms the periphery of the Rāma Yantra. It is divided in twelve parts. Its top has a marble cover which bear scale marks of 360 degrees. It represents the horizon.

The marble faced vertical inner portion of this wall also bears markings of parallel and vertical lines. The base of the instrument which is about four feet above the ground is formed by horizontal slabs of sand-stone also bearing graduations that divide the instrument in twelve sectors from inside. Each slab is like a radius to the circular wall at the centres of which stand a long iron pole. An iron ring at the top of the pole is held by the cross section of eight wires—four indicating four main directions, viz., East, West, North and South and the remaining four indicate four sub-directions viz. 'Agni' between east and south, 'Nairṛta' between south and west; 'Vāyavya' between west and north and Īśāna' between north and east.

The observer can enter inside the instrument from any side for observations and calculations. Both the portions—the vertical

inner wall and the horizontal sectors are graduated by circular (horizontal) as well as vertical lines. The portion from the horizon (at the top) to the bottom of the pole is divided by 90 circular lines, each at a distance of one degree which is sub-divided into 10 parts. Each line is so drawn that it falls parallel to the horizon. These are known as the altitude circles. The same portion is also graduated by 360 lines, known as the azimuth lines, which run straight on the horizontal sectors to rise vertical on the wall, crossing the altitude circles.

The difference between the two Rāma Yantras lies in the difference of the distance between the open portions of the wall in each one. In the eastern instrument it is of 18 degrees while in the western one, it is of 12 degrees. These are, thus, complimentary to each other.

In the south-east of the Rāma Yantra there are two small 'Rāma Yantras'. They were constructed by Maharaja Sawai Jai Singh as models before erecting the main Rāma Yantras. This was the usual practice of the Maharaja to plan the main instruments by raising their models in order to achieve perfection.

13 - B RĀMA YANTRA AT DELHI : (Plates No. 42 & 43)

The Rāma Yantra is situated in the southern part of the observatory. It is in the shape of two circular walls, each of 24 feet 6 inches diameter. Each instrument is divided into 30 sectors of 6 degrees each in such a way that the space in one corresponds with the sector in the other, thus making them complimentary to each other. The inner sectors are raised 3 feet above the ground in order to make any part of the instrument accessible for the purpose of observation at any time during day or night. The observer can enter inside the instrument to place his eye at any part of the graduated sectors for observation of stars and planets. The notches are also provided in between the sectors so that the observer can climb on the sectors to place his eye on any part of

the upper sectors for observing the stars and planets at lower altitudes.

There is a thick pillar of 5 feet 4 inches diameter made at the centre of each of the instruments. Its shadow is observed while falling on the graduated sectors to determine the altitude and azimuth of the Sun. The pillar is divided into 60 parts by 30 strips, each of 6 degrees. The upper rim of the instrument represents the horizon and parallel to it 90 altitude circles, each of 1 degree, are drawn upto the centre of the instrument. 360 vertical lines are also graduated which intersect the altitude circles. These are known as the azimuth lines. The shadow of the central pillar is observed while falling on these graduated sectors, but it is always the centre of the shadow which is taken into account for determining the altitude and azimuth of the Sun. The graduations which were originally done in lime and plaster on the inner surface of the instrument have now disappeared and, therefore, no observation is possible on the instrument now.

Maharaja Sawai Jai Singh planned to construct one more Rāma Yantra at the Ujjain Observatory. A graduated dial like that of the Śaṅku Yantra is situated near the western wall of the observatory. It is believed that this was the plan to make and place an instrument like Rāma Yantra of Jaipur and Delhi for the direct readings of the altitude of heavenly objects. The plan, however, never came to be realised.

PURPOSE OF RĀMA YANTRA :

The altitude and azimuth of stars and planets are determined with the help of these instruments. As each degree is divided into 10 parts, the calculations are correct to decimals.

OBSERVATION DURING DAY : ALTITUDE :

To know the altitude of the Sun, the shadow of the central pole is observed in degrees and decimals thereof, when it falls on the wall of the horizontal sectors. The altitude circles are coun-

ted from the horizon in order to find the altitude of the Sun. If the altitude is observed before noon, it is considered from the eastern horizon and in the afternoon, it is from the western horizon.

AZIMUTH :

The point where the shadow of the pole falls on the graduated wall is marked and counted from the southern most point of the cross-section of wires on the horizon in degrees and their fractions to know the azimuth of the Sun. Exactly at mid-day, the shadow of the pole falls towards the exact north. Then the azimuth of the Sun becomes 180 degrees every day at noon. Thus, the azimuth of planets and stars is counted from the southern most point (where 180 is written) via west, north and so on.

OBSERVATION DURING NIGHT :

The altitude and azimuth of planets and stars are observed also during night on this instrument. For this the observer stands in between the horizontal sectors in such a way that he can see the particular planet or star through the top of the central pole. An arc shaped metal instrument, available in the Jaipur Observatory office, is then placed on the edges of the two sectors over the gap. The same planet or star is again observed from the edge of this metal arc in such a way that heavenly body and the eye make a straight line through the top of the pole. The point from where it is visible is read on the metal arc to find out the altitude of the particular planet or star. The reading then is taken from the southern most point to determine the azimuth of the same during night.

The Local Time can be calculated by logarithm on the basis of altitude and azimuth.

13. DIGAṀŚA YANTRA : The Azimuth Instrument :

Digaṁśa Yantra is an ancient instrument of Hindu origin. It is, in fact, a fixed compass to know directions. As described earlier, it was essential to determine directions for performing the 'yajñas' and other sacred rituals as early as the Vedic times. A vertical gnomon was fixed at the middle of a circle of any radius and its shadow at mid-day was marked for determining North-South. This was determined on the basis of the smallest shadow of the gnomon during day. It is later confirmed by Dhruva, the Pole Star. A perpendicular line on the meridian line would point towards East – West. Besides serving as a stable compass for the Observatory it was also utilised for observing the azimuth of the heavenly bodies with the help of the cross wire shadow.

13 - I. DIGAṀŚA YANTRA AT JAIPUR (Plates No. 44 & 45)

This Azimuth Instrument is situated in the west of the 'Kapāli Yantra (no. 11). It is an open construction of three circular walls. The outer circle is 6 feet 5 inches high and forms a diameter of 27 feet. There are four entrance into it – each one pointing to four directions, viz., north, south, east and west. The inlets take an observer to the next circular wall which is 3 feet $2\frac{1}{2}$ inches high and built on a diameter of 17 feet 6 inches. Finally, the observer gets to the innermost place where a circular structure of the same height as of the middle wall, is built. The circular structure at the centre has a marble covering at its top. On top of the centre of this structure is a knob with two holes meant for inserting a thread at the time of observation.

All the three circular structures have marble roofing at the top and are graduated in 360 equal degrees where each degree is sub-divided into 10 fractions. The graduations on the outer wall are more elaborate where readings are taken at the time of observation.

Two wires are tied between each of the two opposite doors of the outer wall to represent the directions. A small metal ring covers the point where these wires bisect each other. This point is just at the centre of this circular instrument. The knob at the centre of the innermost structure is just below the centre of this ring and, thus, both of them lie in the same vertical plane. This is the smallest Digaṁśa Yantra among all the three built by Sawai Jai Singh in his Stone Observatories.

13 - II. DIGAṀŚA YANTRA AT UJJAIN : (Plate No. 46)

Digaṁśa Yantra or the Azimuth Instrument at Ujjain also consists of three circular walls like its counterparts at the Jaipur and Varanasi Observatories. The diameters of the outer and the middle walls are 32 feet and 20 feet respectively whereas their height is 8 feet 4 inches each. The innermost circular structure at the centre of the Yantra is 4 feet 9 inches high at whose centre a vertical gnomon (a perpendicular iron rod) is provided for the purpose of celestial observations. 360 degrees of azimuth are marked on the top of the circular structure and near the top of the middle wall. There is a small metal disc. attached near the top of the vertical rod bearing 360 degree markings.

13 - III. 4-B DIGAṀŚA YANTRA AT VARANASI : (Plate No. 47)

Like its counterpart at Jaipur observatory, the Digaṁśa Yantra at Varanasi also consists of three circular walls. The diameter of this instrument is 31 feet 6 inches. The outer circular wall is 8 feet 4 inches high and the middle wall and the innermost circular structure at the centre, are each 4 feet 2 inches high. The diameter of the middle circle is 21 feet. An iron rod of the same height as that of the outer wall is on the circular structure at its centre for the observation of its shadow for astronomical readings. It is not provided with the cross-section of two wires holding a metal ring at the centre of the Yantra like the Jaipur Yantra.

All the three circular structures are graduated in 360 degrees each sub-divided into 10 parts.

PURPOSE OF DIGAṀŚA YANTRA :

This is meant for the observation of azimuth of stars and planets during day and night.

The reading of azimuth on the Rāma Yantra is only in degrees whereas on this instrument the same can be read in degrees and their decimals. Secondly, the reading of azimuth on the Rāma Yantra can be verified on this instrument and thirdly, it shows the architectural and astronomical genius of the Maharaja who could give different shapes to the instruments used for the same purpose.

OBSERVATION DURING DAY :

When the azimuth of the Sun is to be determined during day, the centre of the shadow of the ring is spotted on the floor. A thread is tied to the knob, over the circular structure. The thread is then stretched upto the outermost wall in such a manner that it should pass through the very centre of the shadow of the ring as falling on the floor. Already, the outermost circular wall is graduated in degrees and their decimals on its top. Thus the thread touching one of its graduated portions will give the reading which is counted from the southern-most point. This measurement would be the azimuth of the Sun.

The shadow of the metal post provided at the centre of the Yantras at Ujjain and Varanasi is taken into account for the same reading. Though the cross section of wires holding a metal ring at the centre as at Jaipur does not exist there, the method of observation, however, remains the same.

The amplitude (agra) of the sun is also determined by making observations at the time of its rising and setting, since the amplitude is only a particular case of azimuth.

AZIMUTH DURING NIGHT :

As there would be no light at night, it would not be possible to spot any shadow on the floor for the measurement of the azimuth of a planet at night. In this case the observer lies down on the floor and gazes at the planet under study, through the centre of the ring. The vision should be so arranged that the eye, the hole of the ring and the planet under observation, all three should fall in a straight line. The position of the eye is marked on the floor. In case of the Yantras at Ujjain and Varanasi, the planets are observed with the medium of the top of the metal post while making celestial observations lying on the floor of the Yantras. The position of the eye is marked on the floor and rest of the calculations are done likewise.

In a similar way, the thread from the knob should be stretched upto the outermost wall. The point where the thread touches the graduated wall is counted from the southern most point, as already explained, for the measurement of the azimuth of a planet during night.

A peculiar feature of the Digaṁśa Yantra at Ujjain is that it is also used for the altitude readings. For this purpose a 'Altazimuth' device called Turiya Yantra (the quadrant) is fixed on the vertical pole provided at the centre of the circular structure. The Turiya Yantra is arranged in such a way that two holes in it are in line with the celestial body so that it is visible through both the holes. The pointer of the Turiya Yantra moving along the round graduated disc (in 360 degrees) on the top of the pole gives the azimuth readings. The suspending thread of the quadrant attachment provides the altitude of the celestial body on the graduated scale of the quadrant.

14. MIŚRA YANTRA : The Composite Instrument :

Though ancient Indian astronomers were well-versed in drawing meridian circles, Jai Singh imbibed novel ideas in designing and erecting the unique Miśra Yantra. He constructed various meridian circles in such a way that the inclination of their vertical points from the zenith became equivalent to the latitude of their respective places. All this was accomplished by Jai Singh as no reference to such a multi-purpose instrument is available in old Hindu and Muslim treatises. Nor any identical instrument was constructed in any of the old observatories elsewhere in the world. Comprising of five different instruments, the Miśra Yantra has a significant place in the field of observational astronomy. The astronomer - Maharaja chose the Moghul Capital to erect this curious instrument which has become a unique feature of the Delhi Observatory.

1. MIŚRA YANTRA : The Composite Instrument at Delhi (Plate No. 48)

One comes across this Yantra on entering the observatory. It is a combination of five different instruments, hence is named as the Miśra Yantra or the Mix Instrument. This is a unique instrument and has no peer in any other observatory built by Maharaja Jai Singh. On seeing from the south it appears to be in the shape of human heart. It consists of five various instruments as follows :

(i) Dakṣiṇovṛtti Bhitti Yantra : The Meridinal Wall Instrument :

This Small Meridinal Wall Instrument is erected on the eastern wall of the Miśra Yantra. This is the smallest instrument of its kind built by the astronomer-Maharaja. It consists of a small semi-circle which is studded upside down on the wall which accurately lies in the plane of meridian of Delhi. The semicircle is graduated in 180 degrees which are further sub-divided into minutes. There is a hole provided at the centre of the semicircle where a peg is fixed to tie a thread for the purpose of observation.

This instrument is identical in principle, purpose and function to its counterparts at three other observatories. The method of observation is somewhat different here as it is in the form of an inverted semicircle. As mentioned above, a thread is tied to the peg fixed at the bottom and then the thread is stretched to the graduated arc to align it with the Sun exactly at its Meridian Pass Time which can be observed on the nearby Samrāṭ Yantra. The observer has to lie down and look at the Sun with the medium of the peg and the thread. The same process is adopted for the observation of heavenly bodies at night when they cross the meridian.

For the observation on this instrument, two persons are required. One to hold and align the thread with the heavenly object and the other to observe the same from down below. The position of the thread on the graduated arc gives the altitude of the heavenly body at its Meridian Pass Time. Other calculations are done in the same manner as already explained for its counterpart (No. 7) at other observatories. The graduations are done in lime and plaster which can hardly be read now.

(ii) Samrāṭ Yantra : The Equatorial Dial :

This instrument forms the eastern and the western part of the Composite Instrument. Its triangular wall or the gnomon which is placed in the plane of meridian, is separated by the central instrument, known as the Niyat Cakra Yantra. These gnomons make an angle of 28 degrees 39 minutes with the horizon and, thus, are parallel to each other. The western part is meant for the observation before mid-day and the eastern part for the observation after mid-day. The quadrants of the instrument are graduated in 'ghatikās' where one 'ghaṭikā' is equivalent to 24 minutes. Each 'ghaṭikā' is divided into 6 parts, each equivalent to 4 minutes. Again 4 minutes are divided into 10 parts, each part, thus, being equal to 24 seconds. Further division gives the minimum measurement upto

12 seconds on the quadrants. The gnomons are graduated in the scale of tangent for declination observation.

The graduations on its quadrants and gnomons were done in lime and plaster which can hardly be read now as they have been rubbed off by weather and time. In purpose and function, it is identical to its counterpart (No. 1) at Jaipur and other places which may be referred to for details.

(iii) Karka Rāśivalaya : The Cancer (Zodiac) Instrument : (Plate No. 49)

This instrument is in the form of a semi-circle which is based on the wall facing exact North. The semicircle is graduated in 180 degrees which are sub-divided in minutes. The surface on which this instrument is engraved in lime and plaster, is inclined to the vertical plane by (28 deg. 39 min – 23 dig. 27 min. =) 5 degrees 12 minutes which is the Zenith Distance of Cancer. This inclination makes this wall the Cancer Instrument.

When the sign of Cancer culminates on the Local Meridian at a particular time, this instrument is used for finding the longitude of planets. When the Cancer sign of the Zodiac passes the meridian at a particular time during day (that happens for six months in a year), the longitude of the Sun can be found out by observing the shadow of the peg as it falls on the graduated are in degrees and minutes. By dividing the longitude of the Sun by 30, one can also know in which sign of the Zodiac the Sun is passing when the Cancer sign of the Zodiac passes the meridian at a particular time. During night (that happens for other six months), the longitude of planets can be determined with the help of this instrument. This 'Yantra' seems to be the fore-runner of the Rāśivalaya at the Jaipur Observatory which consists of all twelve Zodiac Instruments for determining the longitude and latitude of planets at any time during day and night.

(iv) **Agra Yantra : The Amplitude Instrument** :

North of the western quadrant of Samrāṭ Yantra in the Composite Instrument is another quadrant which lies in horizontal plane and is joined to the gnomon of the Samrāṭ Yantra. This is known as the Agra Yantra or the Amplitude Instrument. The quadrant is graduated in degrees and minutes.

The purpose of this instrument is to show the difference of sun-rise from 6 O'clock. The instrument gives accurate time of sun rise every day and, thus, this instrument is used only at the time of sun rise for about a minute or two.

The shadow of the gnomon falls towards the west at the time of sun-rise. On 21st March and 23rd September it falls on the exact west point indicating sun-rise time as 6 O'clock. On other days of the year this shadow is displaced from this exact west point which is recorded on this instrument. This morning azimuth is also known as the amplitude. The Mathura Observatory also contained a small Amplitude Instrument when it was intact.

(v) **Niyat Cakra Yantra : The Fix or Stable Instrument** :

This heart-shaped instrument is situated right in the middle of the Miśra Yantra. It is a unique instrument and has no parallel in the world. There is a gnomon based on the local Meridian in the shape of a triangle which makes an angle of 28 degrees 39 minutes with the base and points towards the celestial North Pole. There are four semi-circles, two on either side of the gnomon, with their centres falling on the eastern and the western edges of the gnomon where two holes are provided for fixing a pointer or a rod for the observation of its shadow as it falls on the semi-circles.

These semi-circles are made inclined to the plane of Delhi meridian by four different angles, i. e., 75°54' 68°34' W. and 77°16' W., corresponding to meridians of places whose longitudes are different from Delhi by the above given angles. The four international places so represented in this instrument are Green-

which (England) and Zurich (Switzerland) in the West and Notkey (Japan) and Seritchew (Pic Islands in the Pacific) in the East. They all had astronomical observatories.

The purpose of this instrument is to observe mid-day (Noon) at the above mentioned four international observatories and to find the declination of the Sun at 6.52 A. M., 7.24 A. M. and 4.36 P. M. and 5.8 P. M. (Delhi Mean Time). When the pointer is held in the hole on the gnomon at 6.52 A. M. and 7.24 A. M. (Delhi Mean Time), its shadow will invariably fall on the outer and inner semi-circles respectively towards the West. Similarly by holding the pointer on the eastern edge of the gnomon at 4.36 P. M. and 5.8 P. M. (Delhi Mean Time), its shadow will invariably fall on the inner and outer circles respectively towards the East.

The declination of the Sun at the above mentioned timings can be read off on the graduated semi-circles. It may be noted that the shadow of the pointer can be marked on the respective semi-circles only at the above mentioned specific time. Mid-day at the above mentioned places corresponds exactly with the time given above. When the shadow falls on the Western outer circle, it indicates mid-day at Notkey (Japan), when it falls on the western inner circlc, it indicates mid-day at Saritchew (Pic Islands in the Pacific), when the same is observed on the outer and inner circles in the East, it corresponds with the mid-day at Greenwhich and Zurich respectively. This way the Meridian Pass Time of the Sun at these four international places can be observed at Delhi with the help of this magnificent instrument. This is the only instrument in the Delhi Observatory which is restored in marble where the graduations are distinctly marked.

South of the Miśra Yantra is a platform which had a quadrant of 20 feet radius. This was used for making graduations before the same was done on the quadrants and gnomons of the above mentioned instruments. There is, however, no trace of

these experimental graduations on the platform which measures 47 feet by 43 feet.

South-West of the Miśra Yantra are two pillars which were used to suspend an Astrolable in olden days. It is believed that the same Astrolabe was later brought to the Jaipur Observatory. Another significant feature of these pillars is that on the 22nd December which happens to be the shortest day of the year and marks the beginning of the Winter Solstice, the shadow of the round pillar covers the rectangular pillar at mid-day. On the contrary, there is no shadow of the rectangular pillar at mid-day on the 22nd June which happens to be the longest day of the year marks the beginning of the Summer Solstice. This happens due to the 5.2 degree inclination of the rectangular pillar. It may be noted that the Sun is inclined 23.27 degrees north from the celestial equator on the 22nd June and the latitude of Delhi is 28.39 degrees. Hence the pillar is inclined by $(28.39 - 23.27) = 5$ degrees 12 minutes (5.2 degrees) which is the Zenith Distance of the Sun on the 22nd June.

CHAPTER V

HIS FIVE MAGNIFICENT OBSERVATORIES :

1. THE DELHI OBSERVATORY (Plate No. 50)

Altitude	785 feet above M. S. L.
Longitude	77°13′5″ E. of Greenwich
Latitude	28°39′ N.
Mean Difference of Time	– 21 minutes 8 second

The association of the rulers of Amber (former Capital of Jaipur) with the Moghul Emperors had been quite close since Raja Man Singh of Amber. For all succeeding ruler's visits to Delhi were essential to pledge their allegianace and support to the Moghuls. Sawai Jai Singh maintained the same diplomacy. He was one who left a lasting imprint of his wisdom on the court. It is not surprising that he planted his magnificent observatory, the first in the series of his five observatories, on the soil of Delhi.

During his association with Moghul Emperor Muhammad Shah (1719-1748), Maharaja Sawai Jai Singh wanted to prepare new astronomical tables and star catalogues as he found some errors with the existing ones. He wanted to eradicate the errors from the existing tables to attain correct astronomical data. He expressed his views to Emperor Muhammad Shah who encouraged the Maharaja to continue his interest and research in the realm of astronomy in the following words :

"Since you, who are learned in the mysteries of science, have a perfect knowledge of this matter, having assembled the astronomers and geometricians of the faith of Islam and Brahmins

and Pandits and astronomers of Europe and having prepared all the apparatus of an observatory, do you so labour for the ascertaining of the point in question that the disagreement between the calculated times of those phenomena and the times at which they are observed to happen, may be rectified."

The Delhi Observatory, typically known as the 'Jantar Mantar', stands even today in the heart of India's Capital. It forms a curious and picturesque view in the vicinity of the National Parliament. The Observatory is a National Monument which is looked after by the Archaeological Department of Government of India. Some of its 'Yantras' which had become weather beaten were repaired by Pandit Gokul Chand Bhavan under the orders of Maharaja Sawai Madho Singh II of Jaipur in 1910-12 A. D. Except the central part of the Composite Instrument, all the other instruments are in a delapidated condition now. They have almost ceased to function as their graduations have nearly disappeared for want of restoration and maintenance. Inspite of its poor condition, the Delhi Observatory still remains a magnificent monument of ancient science. It provides a fantastic contrast of architecture around it. The modern sky-scrappers have come up in the neighbourhood of this "most surrealistic and logical landscape in stone", thus, providing two styles of architecture which look poles apart.

There is some controversy among the scholars about the date of construction of the Delhi Observatory. According to Pandit Gokul Chand Bhavan, this observatory was constructed in 1710 A. D. but another scholar Syed Ahmed Khan gave its time as 1724 A. D. Most probably the construction of the Delhi Observatory was launched around 1718 A. D. and terminated by 1724 A. D. Sawai Jai Singh took about seven years in preparing his new astronomical tables and star catalogue. Though built on an experimental basis, it suited Jai Singh well and paved the way for other similar astronomical complexes in the country.

All the astro-scholar assistants of Sawai Jai Singh were associated with the Delhi Vedhaśālā. Pandit Jagannath Samrat was the most prominent among them. He recorded the observations here in 1728-29 for Sawai Jai Singh's astronomical tables, known as the 'Zij-e-Muhammad Shahi' after the Moghul Emperor. Pandit Kewal Ram Sharma and Pandit Vidyadhar were the other scholars associated with this observatory during Sawai Jai Singh's times. Most of the European astronomers who visited Jaipur, included the Delhi Observatory also in their itinerary. The French astronomer Father Boudier was one of them. Accompanied by another French scholar, he visited the Delhi Vedhaśālā on his way from Chandernagar (West Bengal) to Jaipur in 1734 A. D. French astro-scholar Tieffenthaler wrote in 1743 A. D. that he made three or four trips to Delhi to meet German astronomer Andre Strobel at the Delhi Obeservatory'. They both made celestial observations in this observatory. Another scholar Monsieur D'Anville also came to Delhi to make observations in 1775 A. D. and wrote that this magnificent observatory was built by the astronomer-Maharaja Sawai Jai Singh of Jaipur and that it was situated in Jaisinghpura in Delhi. He also mentioned about Father Boudier's visit to this observatory. (Monsieur D' Anville as quoted by G. R. Kaye).[1] Pandit Kedar Nath Sharma of Jaipur played an important role in the restoration of the Yantras at Delhi, especially the Miśra Yantra (The Composite Instrument).

1. "Cet habile astronome (P. Boudier) se rendant aux sollicitations d' un puissant Raja nomme Jassing Savae, fort curieux d' astronomie et qui non content d' avoir faire construire un observatoire dans la ville de sa residence a environ cinquante lieues de Delhi en avoit eleve un autre avec magnificence dans un de ces faubourgs qui appele Jassingpura, met 3 minute 40 seconds de difference entre la hauteur rapportee au Palais du Mogol et cet observatoire, ce qui donne un intervaile d' environ 4000 toises".

The Delhi Observatory consists of the following instruments—

No.	Name of the Instrument	Material	Purpose	Accuracy
1.	Miśra Yantra (Composite Instrument)	Stone, mortar and paster	....	....
1-A	Dakṣiṇovṛtti Bhitti Yantra (Meridinal Wall Instrument)	Stone, mortar plaster, also a metal pointer (gnomon)	Latitude of place Length of Day and Night, Rising and Setting Time, Zenith Distance, Altitude and Declination at Noon, etc.	45 seconds.
1-B	Samrāṭ Yantra (Equatorial Dial)	Stone, mortar and plaster	Local Time, I.S.T. Meridian Pass Time, Zenith Distance, Altitude, Declination etc.	12 seconds.
1-C	Karka Rāśivalaya (Cancer Zodiac Instrument)	Stone, mortar and plaster also a metal pointer (gnomon)	Longitude of planets	1/10 degrees (6 minutes or 6 kalās)
1-D	Agra Yantra (Amplitude Instrument)	Stone, mortar and plaster	Observation of Sun-Rise Time, The difference between the Sun-Rise Time and 6 0'clock	12 seconds.

No.	Name of the Instrument	Material	Purpose	Accuracy
1-E	Niyat Cakra Yantra (Fix or Stable Instrument)	Marble, stone, mortar and plaster	Observation of Mid-Day at Greenwich. Zurick, Notkey (Japan) and Seritchew (in the Pacific Ocean)	8 seconds
2.	Bṛhat Samrāṭ Yantra (Big Equatorial Instrument)	Stone, mortar and plaster	Local Time, I. S. T. Meridian Pass Time, Zenith Distance, Altitude, Declination etc.	Not in serviceable condition (2seconds)
2-A	Ṣaṣṭhāṁśa Yantra (Sextaxt)	Stone, mortar and plaster	Rising and Setting Time, Length of Day and Night Altitude, Zenith Distance Declination, Meridian Pass Time etc.	No more in use.
3.	Jai Prakāśa Yantra (2) (The Armillary Sphere Instrument)	Stone, mortar and plaster Original cross-section of metal wires and ring missing. A metal pole as gnomon	Local Time, I.S.T., Altitude, Azimuth, Meridian Pass Time Declination, Longitude, Ascendant and Starting Point of per 10th House of the Zodiac.	Not in serviceable condition.
4.	Rāma Yantra (2) (Altitude/ Azimuth Instrument)	Stone, mortar, and plaster.	Altitude and Azimuth of planets	1/10 degrees (6 minutes or 6 'kalās')

Most of the instruments available in this second largest observatory of the astronomer--Maharaja are identical to those of the Jaipur Observatory. The Yantras at Jaipur are more developed and accurate as they were built after their experimental counterparts at Delhi. The Rāma Yantra at Delhi consists of a thick masonry pillar in the centre and its thick shadow is observed with much difficulty. On the contrary, in the Rāma Yantra of Jaipur, this thick pillar is replaced by a thin metal post whose shadow can be easily and accurately marked on the scales. The Rāma Yantra here is bigger than that at Jaipur and thus is the biggest instrument of its kind in the country. The Samrāṭ Yantra at Delhi is the second highest after its loftiest counterpart at the Jaipur Observatory. The 'Karka Rāśi Yantra' (the Cancer Zodiac Instrument) was the fore-runner of the 'Rāśivalaya' consisting of twelve Zodiac Instruments available at Jaipur. The Dakṣiṇovṛtti Bhitti Yantra and the Jai Prakāśa Yantra at Jaipur were developed on the basis of experiments carried out on the same Yantras at Delhi. The Miśra Yantra or the Composite Instrument is a unique feature of the Delhi Observatory as it is not available in any other observatories. This Yantra consists of five different instruments for various applications and is unique in the world.

2. THE JAIPUR OBSERVATORY (Plate No. 51)

Altitude	1414 ft. above M. S. L.
Longitude	75°49′ 18.8″ E. of Greenwich
Latitude	26°55′ 27″ N.
Mean Difference of Time	-26 minutes 48 seconds

After having successfully experimented with the masonry instruments at the Delhi Observatory, Jai Singh decided to construct a bigger observatory at his new capital Jaipur. He had completed the blue prints and wooden and metal models of his various stone instruments before he shifted his capital from Amber to Jaipur in 1727 A. D. The construction of the astronomical complex was launched in 1728 A. D. and it took about six years in its completion.

Sawai Jai Singh's monumental love for astronomy found expression in the creation of this superb observatory which soon became an institution of observational astronomy. It is situated adjacent to the City Palace, the royal residence of Sawai Jai Singh, to enable the astronomer--prince to carry out celestial observations whenever he wanted. The Jaipur Observatory is surrounded by high walls. Though it is situated in the heart of the city, it seems far from the madding crowd as a perfectly calm and peaceful atmosphere, ideal for the study and observation of astronomical phenomical prevails here. The observatory stands even today as a monument to the Maharaja's scientific approach and great devotion to the ancient science of astronomy.

The observatory fascinated Maharaja so much that he is said to have spent more time here than in his palace. He beautified his new capital by such a magnificent scientific creation which paved the way for the pursuit of astronomical studies and research in the country. The Jaipur Observatory became a venue for astronomical discussions held by Sawai Jai Singh with the Hindu, Arabian and European astronomers. The observatory still serves

as an arena of practical examinations for the students of astronomy. To popularise the study of astral luminaries and to make celestial observations to prepare the ephemeries, calendars and almanacs, Sawai Jai Singh erected the biggest of his five astronomical constructions at Jaipur. The astrological forecasts and interpretations were later based on the astronomical data collected with the help of the masonry Yantras in the observatory.

The Jaipur Observatory consists of the following instruments —

No.	Name of the instruments	Meterial	Purpose	Accuracy
1.	Laghu Samrāṭ Yantra (Small Equatorial Dial)	Sand Stone and marble	Time, Meridian Pass Time, Zenith Distance, Latitude at Noon, Declination etc.	20 seconds
2.	Dhruva Darśaka Yantra (Pole Star Instrument)	Sand Stone	Observation of Pole Star	
3.	Nārivalaya Yantra (Sun-Dial) (2)	Marble and Sand Stone; gnomon of metal	Local Time, Meridian Pass Time, Zenith Distance and Hemispherical Positions.	1 minute
4.	Krāntivṛtta Yantra (Ecliptic Instrument)	Sapta-Dhātu (Seven metals)	Longitude and Latitude of planets	1/6 degrees (10 minutes or 10 kalās)

No.	Name of the instrument	Material	Purpose	Accuracy
5.	Yantra Rāja (Astrolabe)	Metal	Altitude, Zenith Distance, Declination Longitude, Local Time, Ascendant, 4th, 7th and 10th House of the Zodiac etc.	1/6 degree (10 minutes or 10 kalās)
6.	Unnataṁśa Yantra (Altitude Instrument)	Metal	Altitude of the Heavenly Bodies	1/6 degree (10 minutes or 10 kalās)
7.	Dakṣiṇovṛtti Bhitti Yantra(2) (Meridian Wall Instrument)	Marble and Sand Stone, mortar and plaster, metal pegs (gnomons)	Latitude, Length of Day and Night, Rising and Setting Time, Zenith Distance, Altitude, Declination, Meridian Pass Time etc.	1/30degrees (2minutes or 2 kalās)
8.	Bṛhat Samrāṭ Yantra (Giant Equatorial or Equinoctial Instrument)	Marble, stone, mortar and plaster	Local Time, I.S.T. Meridian Pass Time, Zenith Distance, Altitude at noon, Declination etc.	2 seconds
8-A	Ṣaṣṭhāṁśa Yantra (Sextant Instrument)	Marble, stone		1/60 degree (1 minute or 1 kalā

No.	Name of the instrument	Material	Purpose	Accuracy
9.	Rāśivalaya (Zodiac Instruments)	Marble, stone, mortar and plaster.	Longitude and Latitude	1/6 degree (10 minutes or 10 kalās)
10.	Jai Prakāśa Yantra (Armillary Sphere Instrument)	Marble and sand stone, and cross-section of metal wires and metal ring.	Local Time, Altitude, Meridian Pass Time, Azimuth, Declination, Longitude Starting Point of per 10th House of the Zodiac, etc.	1 degree
11.	Kapāli Yantra (hemispherical Bowl)	Marble and sand stone, cross-section of metal wires and metal ring.	Local Time, M.P.T. Azimuth, Longitude, Altitude, Tropical Ascendant etc.	1 degree
12.	Cakra Yantra (2) (Circular Instrument)	Metal Sapta Dhātu (Seven metals)	Declination, Meridian Pass Time, Hour Angles etc.	1/10 degree (6 minutes or 6 kalās)
13.	Rāma Yantra (2) (Altitude/Azimuth Instrument)	Marble stone, mortar and plaster	Altitude and Azimuth of planets	1/10 degree (6 minutes or 6 kalās)
14.	Digaṁśa Yantra (Azimuth-Instrument)	Marble, stone, mortar and plaster, cross-section of metal wires and metal ring	Azimuth of planets	1/10 degree (6 minutes or 6 kalās)

Himself a learned astronomer, Sawai Jai Singh gathered and patronised a number of prominent Scholars of astronomy from all over the country. Pandit Jagannath 'Samrat' of Maharashtra, Pandit Kewal Ram of Gujarat and Pandit Ratnakar Pundarik and Vidyadhar from Bengal were the most prominent among them. They were closely associated with Sewai Jai Singh's observatories and they assisted their master in the construction of his various instruments. The Jaipur Observatory had become an arena of astronomical conferences and seminars where many astronomers and astrologers from all over the country would assemble to exchange their views on the subject. The Jaipur Vedhaśālā soon became the talk of the astronomers and the Mecca for the Indian and continental astro-scholars.

Padre Manuel Figueredo[1] and Fidalgo, and Padre Xavier De Silva were the Portuguese Jesuit astronomers who took long and arduous voyage to meet the Royal astronomer and see his astronomical complex at Jaipur around 1729 A. D. Father Andre Strobel,[2] a German astronomer and Don Pedro De Silva were other European scholars to have come to Jaipur Observatory to make observations. A few years later, the French astronomer' Pere Claude Boudier and a companion undertook a long

1. 'Le Raja d' Amber Jassing—Savae dont les Gazzettes d' Europe firent mention en 1729, du sujet d' un voyage en Portugal' que le Revenend Pere Figueredo, Jesuite Portugais, Fit par ses orders, mourat en 1743,...... ce Prince ayant demande des peres Jesuites de chandernagor l' esperance de le rendre encone plus favourable deux chretiens, en favour de qui il avait deja commence une Eglise dans sa nouvelle ville, determina leur Superieur General dans les Inde a lui en envoyer deux gui partirent de chandernagor de le 6 Janvier de l' annee 1734, et qui firent les observation geographiques qu' on Va rapporter. Ce tour ce que leur a premis de faire en ce genre l'incommodite des voyages en ce pays - ci, sourtout lorsqu'il faut les faire par terre et leur mauvais sante, tout les deux, devant leur retour ayant pense mourir de maladie causee par les fatigues et les mauvais eaux qu on est oblige de boire en chemin."—Lettres Edifiantes et curieuses of Father Boudier.

2 Ibid.

3. "Jai fait trois on quatre excursions d' Agra et Delhi, pour faire visite au R.P. Andre strobel, qui Jessing, Raja de Djepour 'curieux d' astronomie, avait appele'd'allemagne avec un compagnon". Tieffenthaler

and hard journey from Chandernagor (West Bengal) to Jaipur in 1734 A. D. following an invitation from Sawai Jai Singh to visit his observatory . Tieffenthaler was another French scholar who visited the Jaipur Observatory in 1743. He gave his impressions about the Jaipur Observatory as : "But a place that deserves detailed description is that where astronomical observations are made, it is such a work as is never seen in this part of the world and, by the novelty and grandeur of the instruments, strikes one with astonishment. This large and spacious observatory is near the King's Palace. It is situated on a plain surrounded by walls and was constructed especially for the contemplation of stars." The observatory attracted the Muslim astronomers like Muhammad Sharif and Muhammad Mahdi. Thus the Jaipur Observatory had become well-known in the Muslim and European countries even during Sawai Jai Singh's reign (1699–1743 A.D.). Pandit Kedar Nath Sharma was another astronomer-scholar associated with the Jaipur Observatory. He remained its Supervisor for over three decades until he retired in 1953 A. D. Pandit Kanaihaya Lal Shrimali and Pandit Laluji were other prominent scholars of Jaipur associated with the Jaipur Observatory during the reign of Sawai Man Singh II (1922-1947 A. D.)

Scholarly Pandit Kalyan Dutt Sharma, 'Jyotishacharya'. the former Supervisor of the Vedhaśālā, studied astronomy at the local Maharaja Sanskrit College and later taught astronomy in the same College. He has been attached with the Jaipur Observatory as its Supervisor since 1953 A. D. till he retired in 1976. Inspired by the constant observations on the Yantras in the observatory, he has devised a portable multi-purpose instrument known as the Universal Sun-Dial. It gives the readings of the altitude, azimuth, meridian pass time, zenith distance, declination etc. It can also be used with minor adjustments to determine different timings and different positions of stars and planets from anywhere in the world. Pandit Kalyan Dutt Sharma is well-versed in astrology also. Pandit Durga Prasad Dwivedi

and his son Pandit Girija Prasad Dwivedi are the other two local scholars associated with the Jaipur Observatory in the past.

The Jaipur Observatory is a magnificent monument of great historical and scientific value. On entering the premises one is astonished by the novelty and grandeur of the astronomical apparatus scattered over the area. Children mistake if for a children's park due to the weird shape of the instruments. Its surrealistic architecture baffles architects. The mathematicians and astronomers are seen entangled in this cobweb of mathematical precision.

This observatory consists of maximum number (14) of instruments and, thus, is the biggest of all the five observatories of the Maharaja. The observatories at Ujjain, Varanasi and Mathura were based on the instruments of the Jaipur Observatory. They are virtually the miniature models of the big instruments available here. The Samrāṭ Yantra, the Rāma Yantra and the Jai Prakāśa Yantra are the developed versions of their counterparts built at Delhi on an experimental basis. Thus, these instruments look very sophisticated and are accurate in calculations. Other special features of the Jaipur Observatory include the biggest stone instrument, the Bṛhat Samrāṭ Yantra (the Giant Equatorial Dial) which happens to be the biggest instrument of its kind not only in India but in the whole world. The 'Rāśivalaya' or the Zodiac Instruments are also unique here as they are not available in any other observatories in the world. The instruments at the Jaipur Observatory are in perfect working order. They can be used for various celestial observations. The ephemeries are verified here. The Observatory also serves as an arena for the practical examination of the students of astronomy.

The Jaipur Observatory is in a very good state of preservation due to the keen interest taken by the descendants of Maharaja Sawai Jai Singh. The observatory was restored by Maharaja

Sawai Madho Singh II of Jaipur in 1901 A. D. The restoration work was carried out under the supervision of Lieutenant R. E. Garrett, Pandit Chandra Dhar Guleri and Pandit Gokul Chand Bhavan. Since 1948 it has become a National Monument and is being looked after by the State Archaeology Department. This Observatory is known as Vedhaśālā, Yantraśālā and Yantrālaya in Hindi. It is popularly called as 'JANTAR-MANTAR' as 'Jantar' stands for Yantra (instrument) and 'Mantar' for mysterious calculations.

THE UJJAIN OBSERVATORY (Plate No. 52)

Altitude	1500 feet above M. S. L.
Longitude	$75^{\circ}45'$ of Greenwich
Latitude	$23^{\circ}10'$N
Mean Difference of Time	–27 minutes

Ujjain is to India what Greenwich is to the world. The ancient Hindu astronomers regarded Ujjain as situated on the Prime Meridian (Zero Longitude) and various astral calculations were done with reference to the Meridian of this place. In the 'Sūrya Siddhānta' Ujjain is referred to as situated on the line which passes through the haunt of demons (Lanka) and the abode of gods (Mount Meru). Varāhamihira mentioned in his 'Pañca Siddhāntikā' that Lanka and Ujjayani were situated on the same meridian and the noon at the two places occured at the same time. Bhāskarācārya II also mentioned Ujjain in many other astronomical references as the place of zero longitude and calculated its latitude as 'one sixteenth of the whole circumference north of the equator' which is equivalent to $22^{\circ}30'$. It was believed in ancient times that the sun changed its course towards South after completing its farthest North journey near the Zenith point of Ujjain. It was the same point where the meridian line of ancient Lanka crossed the Tropic of Cancer and, therefore, the meridian line of Ujjain became the Prime Meridian (Longitude Zero$^{\circ}$) of India.

Called as Avanti or Ujjayani in ancient times, the city has been known for top experts in various fields of learning mainly because of some of its rulers who had a penchant for expanding knowledge, prominent among them being King Vikramāditya. Varāhamihira, a renowned astro-scholar lived somewhere in the cobbled streets of this beautiful town in the sixth century A. D. during the Gupta period. Brahmagupta was another erudite scholar who was also associated with this ancient citadel of learning. He taught astronomy and mathematics here in the seventh

century A. D. Brahmagupta founded the traditions of observational astronomy which were later adopted by Sawai Jai Singh. According to a legend, Guru Sandipani's 'āśrama' where Lord Krishna pursued learning in the pre-historic times, was situated in Avanti. Astronomy reigned supreme at Ujjain. Notable astro-scholars possessing an exacting sense of subject held parleys for astronomical studies and celestial observations here.

Another significant astronomical feature of ancient Ujjain is that the two important Hindu Eras, viz., the 'Vikrama Saṃvat' prevalent north of the Narmada and the Śaka of the south, originated here. The Saṃvat era was introduced by King Vikramāditya I in 57 B. C. The Śaka era was heralded in 78 A. D. Both the eras are followed all over the country even today. This quiet town located in central India still bears some of the ancient relics. It is one of the supreme seats of Lord Shiva—the Mahākāla or the Mahākāleśvara— in the country.

Himself an ardent follower of Indian ethics, Sawai Jai Singh of Jaipur truly realised the importance of Ujjain and decided to construct one of his 'Jantar Mantars' here. In a way, the Jaipur ruler of the eighteenth century gave a new prestige to reckon this place. He acted as a renaissance hero and popularised this seat of Oriental astronomy. His name was, thus, added among the gallaxy of astro-scholars associated with Ujjain.

Ujjain's location in close proximity of the Tropic of Cancer gave it a rare distinction as compared to rest of the four places where the Sawai made his 'Jantar Mantars' in the northern portion of the country. This geographical phenomenon was well availed of by astronomers since the olden days. They made ephemeries here basing astral calculations as per movement of the sun from the Tropic of Cancer. Ujjain thus became famous all over India for its Hindu ephemeries. Even today, this reputation is held true. The position of Ujjain has, however, changed in regard to the Tropic of Cancer due to slow diminution per year

in the maximum obliquity of ecliptic. As a result the sun goes North from the Zenith of Ujjain. Since the position of the Observatory is before the Tropic of Cancer the sun comes on the Zenith here on the 13th June at the time of Transit. Its situation of neighbourhood with the Tropic of Cancer is sufficient to make the City hub with astronomical activities.

The Jantar Mantar is ideally situated on the southern fringe of Ujjain on the bank of the quiet flowing Kshipra. Amidst sylvan surroundings stand the intricate masonry structures deciphering the geometry of astronomy here. Each of the five masonry instruments is in fine shape as the State Education Department manages its affairs and keeps the things ship-shape. Formerly known as the Hindu Vedhaśālā and the Jantar Mahal, the Ujjain Vedhaśālā is the only working observatory in the country.

The Ujjain Observatory consists of the following instruments --

No.	Name of Instruments	Material	Purpose	Accuracy
1.	Samrāṭ Yantra (Equatorial Dial)	Stone, mortar plaster and marble	Local Time I.S.T. Meridian Pass Time, Zenith Distance, Altitude, Declination etc.	20 second
2.	Dakṣiṇovṛtti Bhitti Yantra (Meridinal Wall Instrument)	Stone, mortar plaster and marble (metal gnomons)	Rising and Setting Time, Length of Day and Night Altitude, Zenith Distance etc.	1/30 degree
3.	Nārivalaya Yantra (Sun-Dial)	Stone, mortar plaster and marble (metal gnomon)	Local Time, I.S.T. Meridian Pass Time Hemispherical positions etc.	3 minutes

No.	Name of the Instrument	Material	Purpose	Accuracy
4.	Digaṁśa Yantra (Azimuth Instrument)	Stone, mortar and plaster (metal gnomon)	Azimuth	1/10 degree (6 minutes or 6 kalās)
5.	Saṅku Yantra (Gnomon Instrument)	Stone, mortar plaster, metal gnomon	To trace Sun's path	

There are different opinions about its construction. An inscription on the Meridinal Wall Instrument suggests that the Ujjain Observatory was constructed in Saṁvat 1776 (1719 A. D.) which seems improbable. According to G. R. Kaye it was built between 1728 and 1734 A. D. The fact is that it was constructed by Sawai Jai Singh when he was the Governor of Malwa. Being the chief-de-mission of all regal 'bandobast' in the Malwa region. Jai Singh had to make frequent visits to this black-soil tableland. From 1713 to 1729 was a period when he was busy quelling certain regional battles. Thus he got an opportunity to assess the astronomical potential of Ujjain. The work on the Jantar Mantar was started by him in 1733 and completed in 1734. It was the third construction in the series of his five observatories in the country, Delhi and Jaipur being the first and second respectively. Jai Singh loved the place and stayed in Ujjain to make astronomical observations at the Jantar Mantar and thus helped to correct the astronomical Tables. It was he who found out the correct latitude of Ujjain—23°10′.

A mention of this observatory is found in an account given by Tieffenthaler, a Jesuit priest who travelled in India from 1743 to 1786 A. D. Dr. William Hunter visited this site in 1792 A. D. and gave a brief description of this Observatory in the Asiatic Researches. He found the place 'roofed with tiles and converted

into the abode of a Hindu Deity.' A Hanuman shrine still stands towards the western wall of the Vedhaśālā proving Hunter's account.

The observatory remained neglected for nearly two hundred years until it caught the attention of Maharaja Sawai Madho Singh II of aipur who sent his learned Court-astronomer, Vidyabhushana Pandit Gokul Chand Bhavan in 1922 A. D. to restore the Vedhaśālā on the lines of the Jaipur Observatory. It may be recalled that it was the same Maharaja who undertook the restoration of other Vedhaśālās raised by his glorious ancestor Sawai Jai Singh. Before the Ujjain Vedhaśālā could be restored to its original grandeur, Maharaja Madho Singh of Jaipur passed away in 1922 A. D. His death created problems for the restoration and maintenance of Ujjain Vedhaśālā.

The mantle then fell on those who ruled this part of the country. The then Maharaja Madhav Rao Scindhia of Gwalior was sounded by some scholars about giving a face-lift to this structure in view of its immense benefit to the country. Shri Sandipana Vyas 'Siddhānta Vāgīśa', Nārayanji Vyas, G. S. Apte and others were among those who drew the attention of the illustrious Gwalior prince. The scene thus shifted from the Jaipur House to the Gwalior House, which readily made available some funds to refurnish the Observatory. The restoration work was completed in 1926. The Maharaja got keenly interested in it and he even reorganised the Vedhaśālā to make best use of its instruments. The almanacs were based on actual observations as a result and Ujjain's prestige as the seat of learning could be upheld to a great extent. The Observatory thus came to be known as 'Jeewaji Vedhaśālā' when Maharaja Jeewaji Rao Scindhia succeeded his predecessor King.

Ujjain lured many a scholar mainly because of its observatory remaining in excellent working condition following the noble gesture shown by the Gwalior House. The history made a

tangent at this stage when most of those associated with the Observatory took it for granted that Jaipur Prince had nothing to do with it it was the Gwalior State Government which was known for its up-keep.

Tieffenthaler and Dr. William Hunter are among the foreign scholars who visited and made observations in this observatory as early as the late eighteenth century. Madhav Rao Scindhia invited Pandit Kedar Nath Sharma, a learned astronomer from Jaipur in 1934, who was consulted by the erstwhile government of Gwalior regarding its restoration, maintenance and organisation. Govind Sadashiv Apte was perhaps the most prominent scholar attached to it as its Superintendent from 1927 to 1936. It was he who masterminded its reorganisation into a working observatory. He left the lasting print of his Wisdom by adding the Śaṅku Yantra to the Vedhaśālā in 1937 A. D. G. S. Apte was succeeded by R. V. Vaidya who made plans for its development and implemented them when he was the Superintendent during 1936-1952 A. D. He was followed by D. K. Bellakar (1953-1956) and Purushottam Joshi (1956-1961). Pt. Tej Karan Acharya was another scholar supervising this observatory during 1962-63, who was later succeeded by, learned Pandit Kamala Kant Joshi 'Jyotish Shastracharya' who is looking after this scientific establishment as its Superintendent at present.

An astronomical ephemeries of geo-centric places of planets is published by this scientific establishment every year. Some of these almanacs and ephemeries published by the Ujjain Observatory are considered as the most authentic. The Observatory is administrated by the Education Department of Madhya Pradesh these days. It has thus been maintained as an educational activity and not confined as a mere relic of the yore. Students of astronomy visit this place for practicals. The State Meteorological Department further installed some instruments to further add to its practical uses. The instruments to record

the direction and velosity of wind all the twenty four hours are placed on top of the Meridinal Wall Instrument whereas a rain gauge is kept north of the Vedhaśālā Office.

The 'Jyotiṣa Yantras' at the Ujjain Vedhaśālā are identical to their counterparts available at Jaipur. This Vedhaśālā has the smallest Nārivalaya Yantra (Sun-Dial) though its Digaṃśa Yantra (Azimuth Instrument) happens to be the biggest of all the three such Yantras built by Sawai Jai Singh. The Bhitti Yantra (The Meridinal Wall Instrument) at Ujjain is also the loftiest and the most accurate of its other counterparts existing at Delhi, Jaipur and Varanasi.

4. THE VARANASI (BENARAS) OBSERVATORY

(Plate No. 53)

Altitude	350 feet above M.S.L.
Longitude	83°2' E. of Greenwitch
Latitude	25°20' N.
Mean Difference of Time	2 minutes 8 seconds

Varanasi, the very name sprouts some religious fervour. It is a great traditional centre of art, culture and learning. It is another famous seat of Lord Shiva, known as Vishwanatha. This ancient place has the holiest helo around its every aspect. For Hindus it's a place where a dip in the Ganges washes away all sins, the Ganges to which 'So many generations of men have looked for inspiration, at whose shrines they have quickened their faith', to quote late Sir Maurice Gwyer. It also bears a strong Buddhist cult for Lord Buddha gave his first sermon at Sarnath, near here. Known in ancient times as Kashi and in Sanskrit Varanasi, Banaras, by all means, was the epic centre of all learning. Studies of Vedānta, Sanskrit classics and ethics were carried out here. Scholar Pandits and other Brahmins trekked from all sides especially to undergo the classics taught only here in the ancient days. Astronomy was another attraction for them.

Sawai Jai Singh who had dubbed himself into the classics did not leave Varanasi out of his astronomical peripheri. He left his lasting foot-prints by raising an observatory here on the bank of the Ganges to add a scientific dimension to this important place. He gave to the theory makers the practical, the authentic and the rational by this scientific creation. Indeed the observatories at Ujjain and Varanasi have stood as places of utmost benefit to the scholars as both these places were associated the most with astronomy.

The astronomer-assistants of Sawai Jai Singh were also associated with this observatory. Pandit Jagannath Samrat and Pandit Kewal Ram assisted Sawai Jai Singh in its construc-

tion in the year 1737 A.D. The foreign missionary scholars who visited the Jaipur and Delhi Observatories are believed to have visited the Varanasi Observatory as well. Pandit Gokul Chand Bhavan, the state-astronomer of Maharaja Sawai Madho Singh II of Jaipur, had played a key role in its restoration in 1911 A.D. Pandit Sudhakar Dwivedi, Ramvyas Pandey, Vindheshwari Prasad and Ramyatna Ojha were other scholars of Banaras associated somehow or the other, with the Kashi Vedhaśālā during the nineteenth and the twentieth centuries.

The observatory was built in 1737 A. D. on the terrace of Man Mandir which was built by Raja Man Singh of Amber in the sixteenth century. This edifice is situated on the famous Manikarnika Ghat on the west bank of the Ganges. The masonry Yantras are raised over looking the holy Ganges. Even today it is one of the most interesting places of sight-seeing in Banaras. It was repaired by the orders of Maharaja Sawai Madho Singh II of Jaipur in 1911 under the superintendence of Lala Chimanlal Darogha Imarut of Jaipur and by Pandit Gokul Chand Bhavan, the State Astronomer of Jaipur.

The Banaras Observatory consists of the following instruments—

No.	Name of the instrument	Material	Purpose	Accuracy
1.	Samrāṭ Yantra (Equatorial Dial)	Sand Stone, mortar and plaster.	Local Time, I.S.T. Meridian Pass Time, Zenith Distance, Altitude, Declination etc.	15 seconds
2.	Laghu Samrāṭ Yantra (Small Equatorial Dial)	Sand Stone, mortar and plaster.	Local Time, I.S.T. M.P.T., Zenith Distance, Altitude, Declination etc.	1 Minute

No.	Name of the Instrument	Material	Purpose	Accuracy
3.	Dakṣiṇovṛtti Bhitti Yantra (2) (Meridinal Wall Instrument)	Sand Stone, mortar and plaster-gnomons (pegs) of metal.	Latitude of place, length of Day and Night Rising and Setting Time, Zenith Distance, Altitude, Declination etc.	1/6degree (10minutes or 10 kalās)
4.	Nārivalaya Yantra (sundial)	Sand Stone-gnomon of metal	Local Time, Meridian Pass Time, Zenith Distance and Hemispherical positions.	1 minute
5.	Digaṁśa Yantra (Azimuth Instrument)	Sand Stone	Azimuth	1/10 degrees (6 minutes or 6'kalās')
6.	Cakra Yantra (Circular Instrument)	Metal	Declination Meridian Pass Time, Hour Angles.	1/10 degrees (6 minutes or 6 'kalās')

All the six instruments in this observatory also are identical to their counterparts in the Jaipur Observatory. The Digaṁśa Yantra (the Azimuth Instrument) here is bigger than that of the Jaipur Vedhaśālā. It has a metal post fixed at the centre of the instrument whereas at Jaipur one finds a cross-section of wires holding a metal ring at the centre, though, in both cases, their shadow is similarly observed. This Vedhaśālā has the smallest of all the seven Samrāṭ Yantras built by Jai Singh in

his observatories. At present, this is the only observatory, situated on the terrace of a historical edifice, which is its unique feature. This Observatory has not yet been recognized as a National Monument and is still looked after by the Household of the former Maharaja of Jaipur.

The observatory has the following stone inscription which erroneously gives the date of its first construction as 1710 A.D. This discrepancy could naturally occur as the inscription was put at the time of its renovation in 1911.

Man Mandir : This building was erected by Raja Man Singh about the year 1600 A.D. and was used as an observatory in the time of his descendant Sawai Jai Singh, the founder of Jaipur.

THE BANARAS OBSERVATORY :

This observatory, originally constructed by Maharaja Sawai Jai Singhji of Jaipur in A.D. 1710 was restored in 1911 A.D. by the order of Major General His Highness Saramad-i-Rajah-i- Hindustan Raj Rajinder Sri Maharajadhiraj Sir Sawai Madho Singhji Bahadur Knight Grand Commander of the Most Exalted Order of the Star of India, Knight Grand Commander of the Most Eminent Order of the Indian Empire Knight Grand Cross of the Royal Victorian Order Donat of the Order of the Hospital of Ist John of Jerusalem, Doctor of Laws (Edin) of Jaipur conveyed by Mumtazudoulah Nawab Sir Mohmed Fyazali Khan Bahadur, Minister K.C.I.E. K.C.V.O., C.S.I., through Rai Bahadur Khawas Bala Bakhsh under the superintendence of Lala Chiman lal Darogha Imarut of Jaipur Lala Chandulal Overseer. Pandit Gokul Chund State Astronomer, Bhagirath Mistri.

5. THE MATHURA OBSERVATORY

Altitude	600 Feet above M. S. L.
Longitude	77°42' E. of Greenwitch
Latitude	27°28' N.
Mean Difference of Time	–19 minutes 12 seconds.

The cruel hands of time have snatched away one of the five magnificent observatories from us. Not even a debris of the observatory is available at Mathura where Sawai Jai Singh built a number of instruments. This was his last astronomical construction in the series of five observatories. For this purpose, he chose a Fort, built by his ancestor Raja Man Singh of Amber towards the end of the sixteenth century.

The observatory at Mathura was located on the bank of the Yamuna. Mathura, situated on the Delhi-Agra Highway, is associated with Lord Krishna's childhood. Sawai Jai Singh, who was a staunch devotee of Lord Krishna, used to visit Mathura often. He had built a temple of Lord Krishna, better known as Govind Devji, that exists even today near the City Palace in Jaipur. The idol was brought from Vrindaban near Mathura when that holy place was threatened by the bigot Aurangzeb. Sawai Jai Singh used to pass through Mathura often when he travelled between Delhi and Agra as the Governor of Agra and Malwa. Being a sacred place, Mathura was frequented by a great many Hindu Pandits and Brahmin astronomers-astrologers for pilgrimage. Thus, he realised the political and religious importance of the place and thought of providing the fifth and the last of his Vedhaśālās here.

Not much information is available about the Mathura Observatory as its venue the Mathura Fort, was slowly demolished as this ancient holy city withstood repeated attacks by religious fanatics. The last remains of this observatory were sent into oblivion sometime during the 1857 struggle. Jyoti Prasad, a

contractor had bought the Fort from the Government about 1857 A. D. and demolished a major part of it, thus destroying the very existence, every bit, of the Mathura Vedhaśālā which was located on the terrace of a building in the Fort. There were Agra Yantra (the Amplitude Instrument), Laghu Samrāṭ Yantra (smaller version of the Equatorial Dial), Dhūpa Ghaḍī (the Horizontal Sun-Dail), Dhakṣiṇovṛtti Bhitti Yantra (the Meridinal Wall Instrument) and some other small instruments which were constructed on an elevated space. They were made of brick, mortar and plaster. Stone was not much used in these instruments as brick constructions have been customary in this part of the country. The Fort, known as 'Kans-ka-Kila' stands in the pages of history only.

The Mathura Vedhaśāla had a similar situation like that of Varanasi. Both Vedhaśālās were constructed on the terrace of the edifices built by Raja Man Singh of Amber. All the Yantras built here were the smaller versions of the Yantras available at the Jaipur Vedhaśālā. This was the smallest of all the observatories erected by the astronomer-Maharaja of Jaipur.

Catalogue of Manuscripts on astronomy on display in the Maharaja of Jaipur Museum Library—City Palace, Jaipur.

Sanskrit

1.	Arishtakartriyoga-phalam	1729 A.D.
2.	Ukaragranthah—Nayanasukhopadhyayah	19th C.
3.	Kalnivyayasangrahah—Bhattoji Dikshita	20th C.
4.	Grahayogaphalam	18th C.
5.	Zica-Ulughabegi	1727 A.D.
6.	Zica-Nityanandi Shahajahani—Nityanadah	19th C.
7.	Dvighatika-muhurtam—Shivah	19th C.
8.	Nakshatrabekhanam	1842 A.D.
9.	Nakshatravicharah	1770 A.D.
10.	Pavanvijaya-svarodayah	
11.	Pashakevali	18th C.
12.	Pitamahasiddhantah	18th C.
13.	Prashna Kerali and Rama Kerali—Ramchandrah	19th C.
14.	Prashnachudachakram	1885 A.D.
15.	Prashnasudhah-Vasavanandah Kavih	1903 A.D.
16.	Bhasvati-tika—Satanandah	19th C.
17.	Margashirsakshayamasa Vivarandon	1822 A.D.
18.	Yantraprakarah	18th C.
19.	Yantraraja-risale-Bisa-baba	18th C.
20.	Yogarnavah—Venkateshah	19th C.
21.	Ratnadyotah—Gangaramah	19th C.
22.	Laghujataka-tika—Utpala Bhattah	19th C.
23.	Vakramargavicharah	18th C.
24.	Virodhamardana Granthah—Yajneshvara —Punekara Jyotirvit	1837 A.D.
25.	Sharaha-tazkarah Varjandi Nayanasukhopadhyayah	1729 A.D.

26.	Shivalikhitam	20th C.
27.	Svapnadhyayah—Brihaspatih	19th C.
28.	Svarodaya-tika	19th C.
29.	Somasiddhantah	1679 A.D.
30.	Pratapa-martanda (Hindi)—Ganapati Bharati	19th C.

Persian and Arabic Manuscripts :

31.	Zica Shahajahani (Karnamah Saheb Qiran; Sarani Shahajahani)—Ibrahim Dehlvi	17th C.
32.	Tahfim-ul-avval (Sana-at-ul Tanjim) —Abu Rehman Mohammad bin Ahmad S/o Alberuni	1491 A.D.
33.	Taharir-ul-Majisti (Hakim Batati Musa Yunani and Arasta-talis Aristotle)	16th C.
34.	Taharir-ul-Majisti „ „	16th C.
35.	Manazar-e-ibn-e Hastim-Ibn-e Hisham Hashim	1672 A.D.
36.	Risalajat-ul Kurst etc. (risala ayat-al Kursi)	1524 A D.
37.	Lavahe-ul Qamar	1667 A.D.
38.	Sharah-e Cighmani Muhammad bin Umar Cighmani	16th C.
39.	Sharah-e Zica Mirza Ulughbeg Mirza Ulughbeg bin Shahrukh bin Timur of Gorgan	1732 A.D.
40.	Sharah-e Tazkirah Mulla Nazam Mulla Nizam Hasan bin Mohammad Neshapuri alias Nizam Naimullah	16th C.
41.	Sharah-e Tazkirah Mulla Nizam Mulla Nizam Hasan bin Mohammad Neshapuri alias Nizam Naimullah	16th C.
42.	Sharah-Shamsiya-hisab Maulana Ali Barjandi Abdul Ali ibn Mohammad bin Al Husain Barjandi	1517 A.D.
43.	Rozat-ul-akhyar Mohammad bin Qasim bin Yakub	17th C.
44.	Jam-e Shahi	17th C.
45.	Zica Ulughbegi Mulla Chand ibne Bahauddin	16th C.

46. Zica Khaqani Ailkhani Jamshed bin Masuda bin Mahamud alias Ghayas-at Sadullah Tabib Kashmiri — 1425 A.D.

47. Zica Muhammad Shahi — 18th C.

48. Zica Muhammad Shahi (copy) — 18th C.

49. Zica Barjandi–Abdul Ali bin Mohammad Husain Barjandi — 1608 A.D.

50. Zica Shahajahani (Sarani)—Ibrahim Dehlvi — 1628 A.D.

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51. Historide Coelestics Britannical -observanate Johannes Flamsteed-ius Derbiensis — 1725 A.D.

52. -do- Vol. Tertium -do- — 1735 A.D.

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   II. Stellarum and Fixarum

   III. Claudi : Ptolemaei and Ulughbeghi-fixarum catalogii

   IV. Tabulae Astronomical

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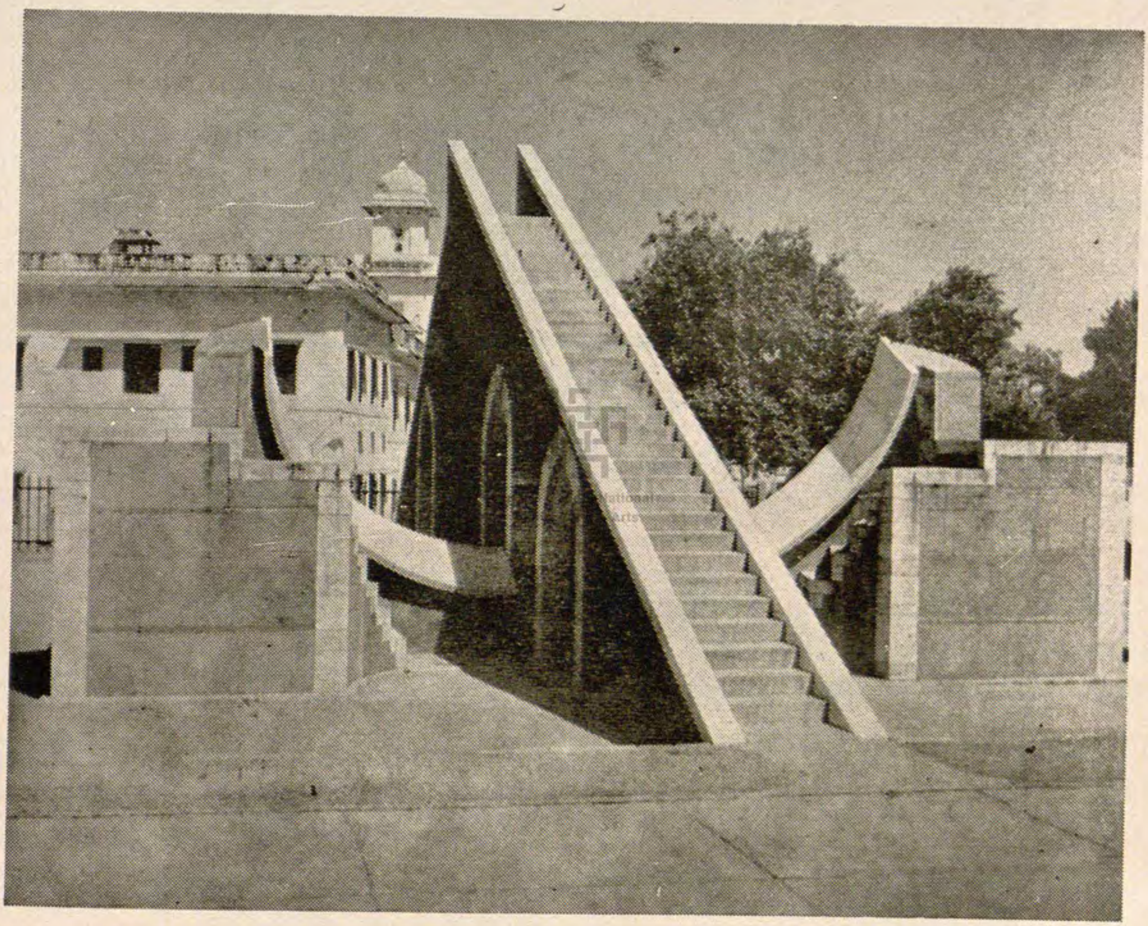
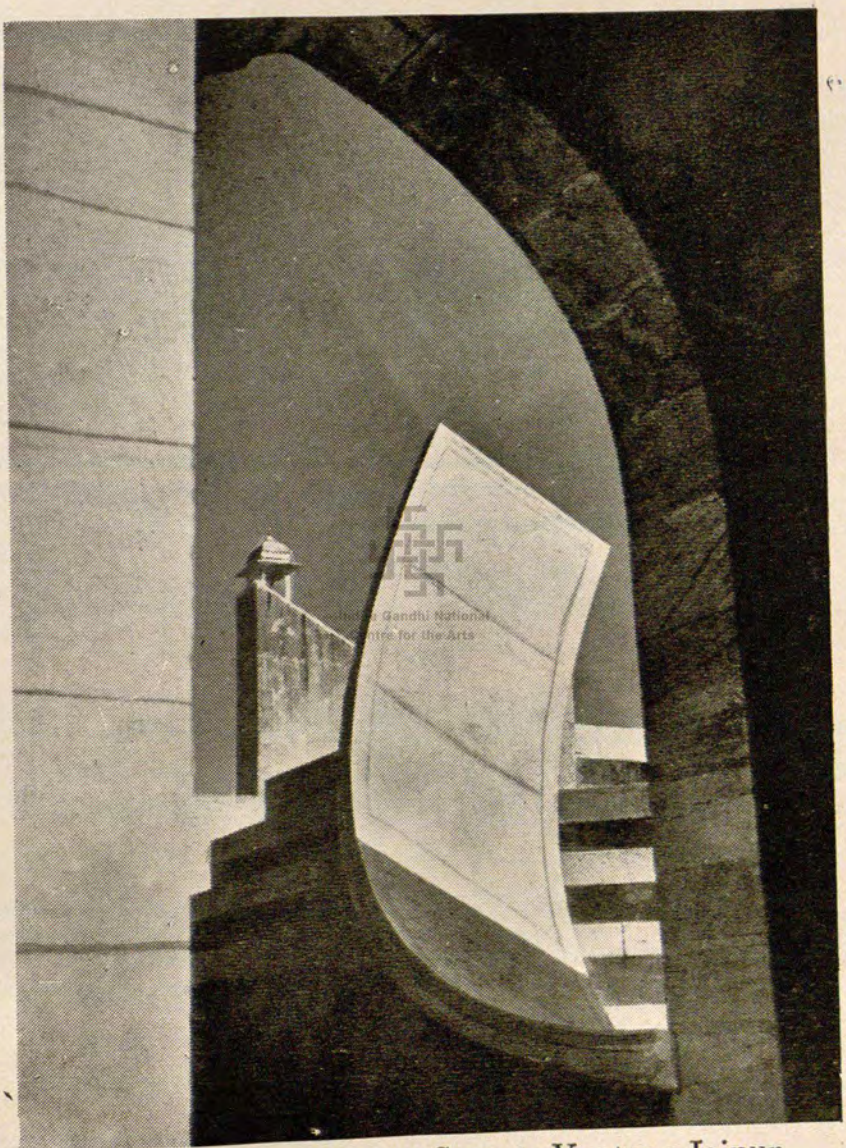
Pl. 1A Maharaja Sawai Jai Singh of : Jaipur (1699 – 1743)

Pl. 1B Maharaja Jai Singh of Jaipur, conversing with Father Manuel De Figuerido S. J. and a Portuguese Fidalgo, who arrived from Portugal in 1729. The Father presented the Maharaja with some astronomical charts and books. They are seen in the grounds of the Jaipur Observatory.

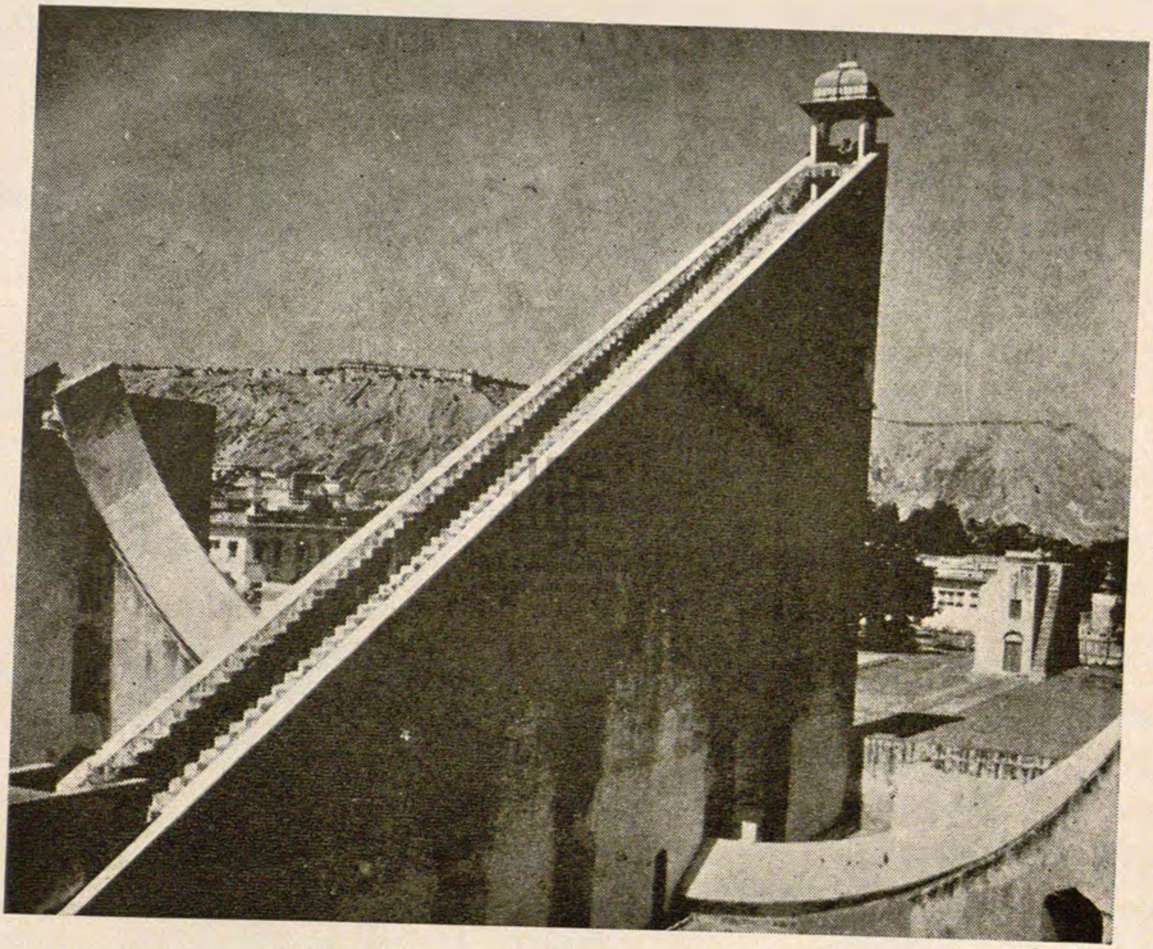
—Courtesy, Maharaja Sawai Man Singh II Museum Trust



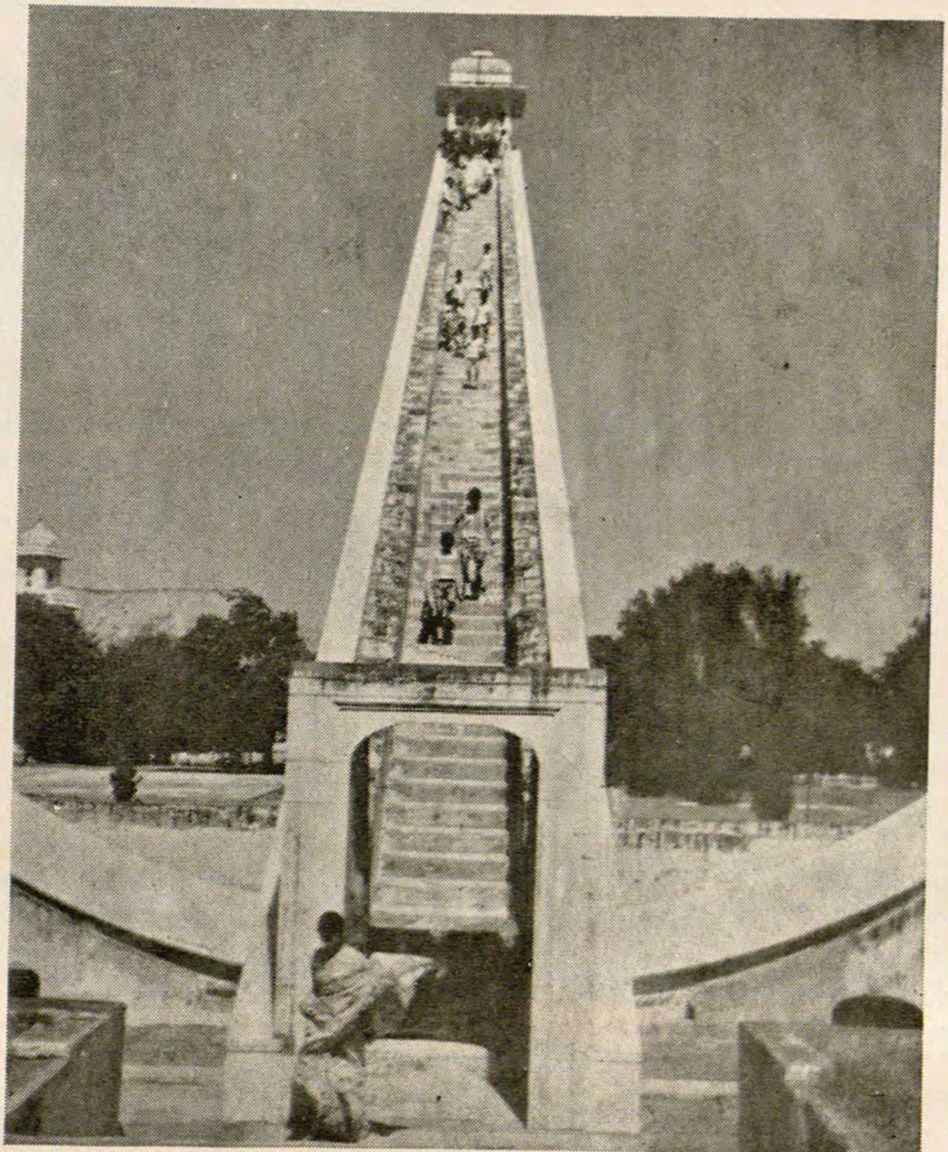
Pl. 2 Laghu Samrāṭ Yantra : Jaipur



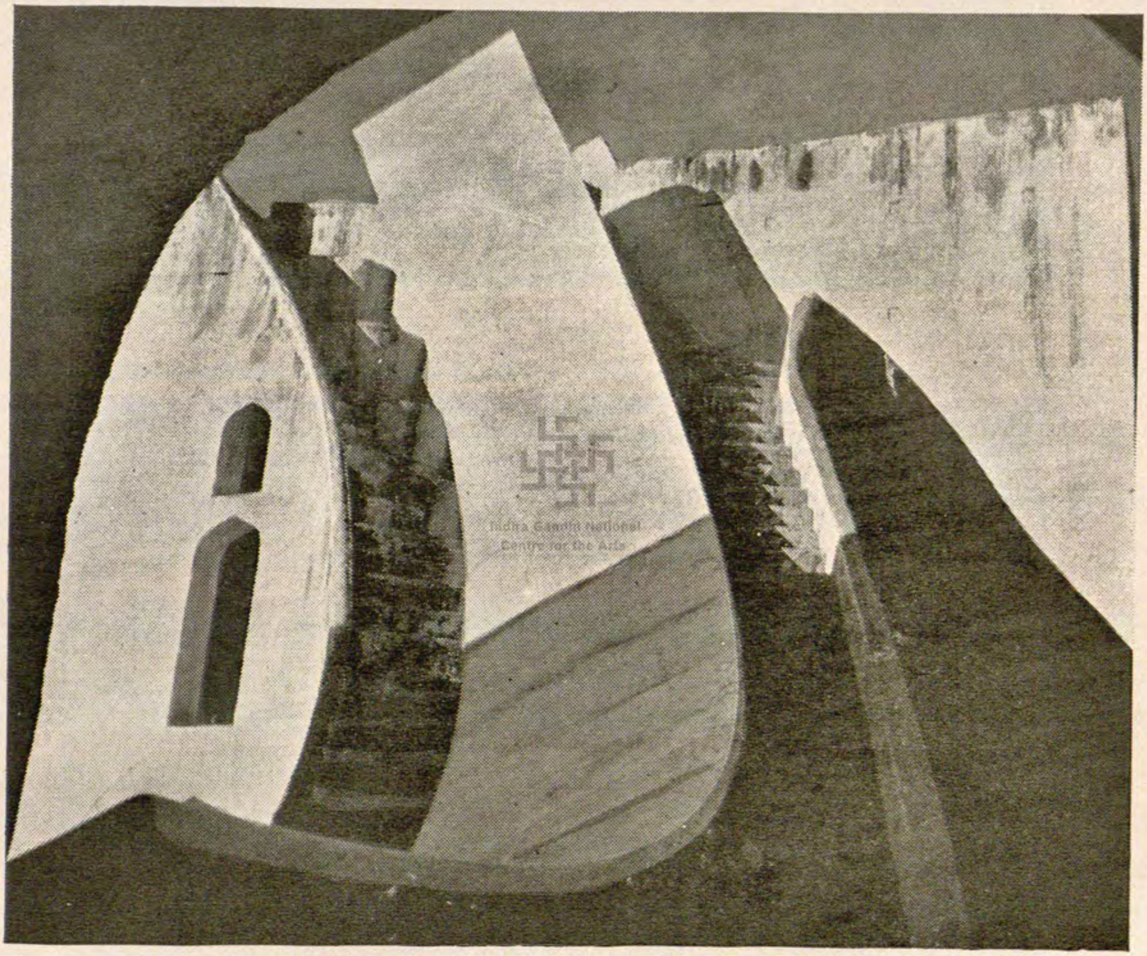
Pl. 3 Quadrant--Laghu Samrāṭ Yantra : Jaipur



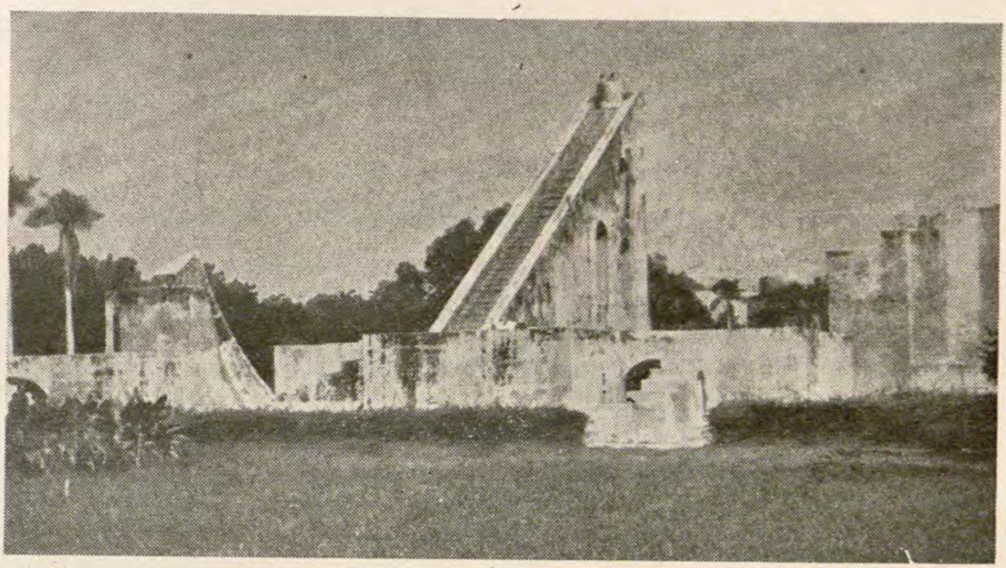
Pl. 4 Bṛhat Samrāṭ Yantra : Jaipur



Pl. 5 The Gnomon of Bṛhat Samrāṭ Yantra : Jaipur

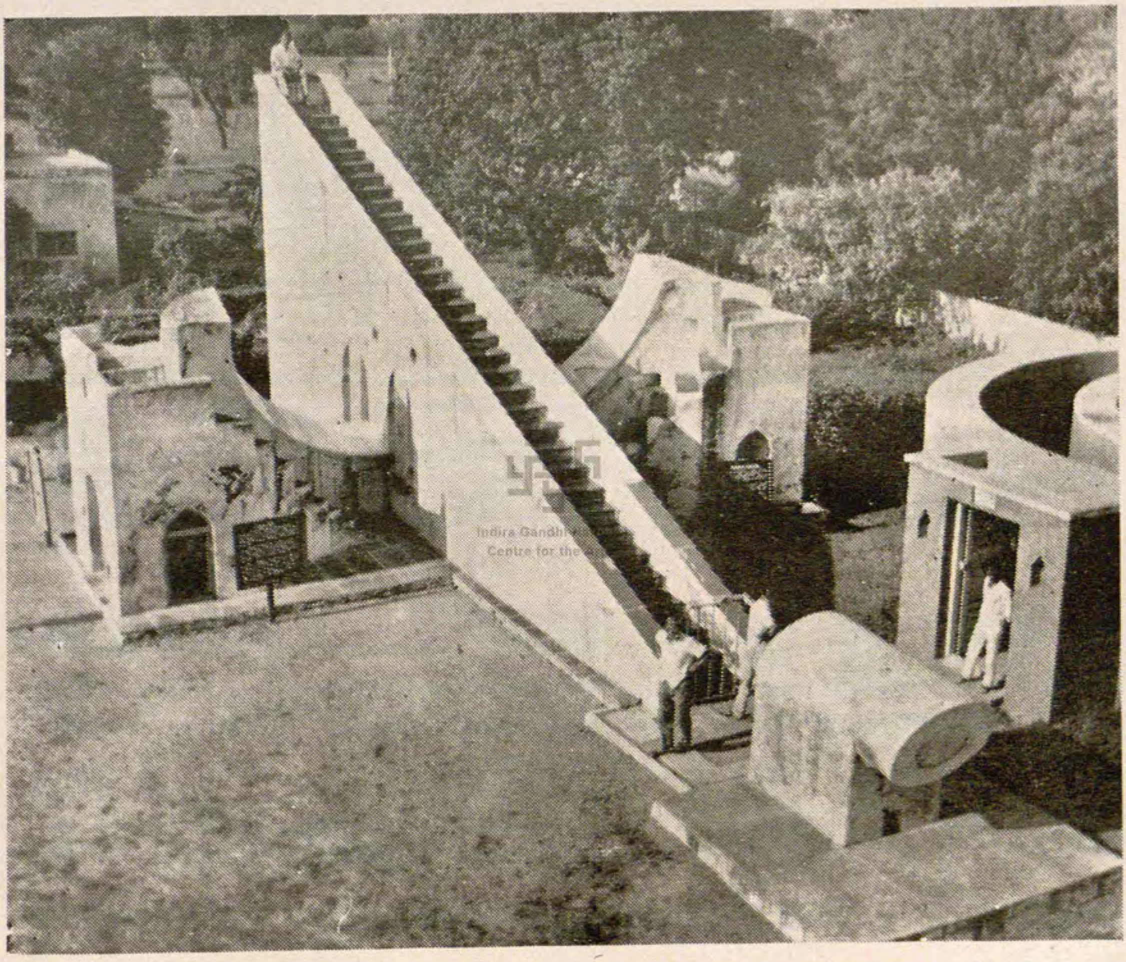


Pl. 6 The Quadrant of Bṛhat Samrāṭ Yantra : Jaipur

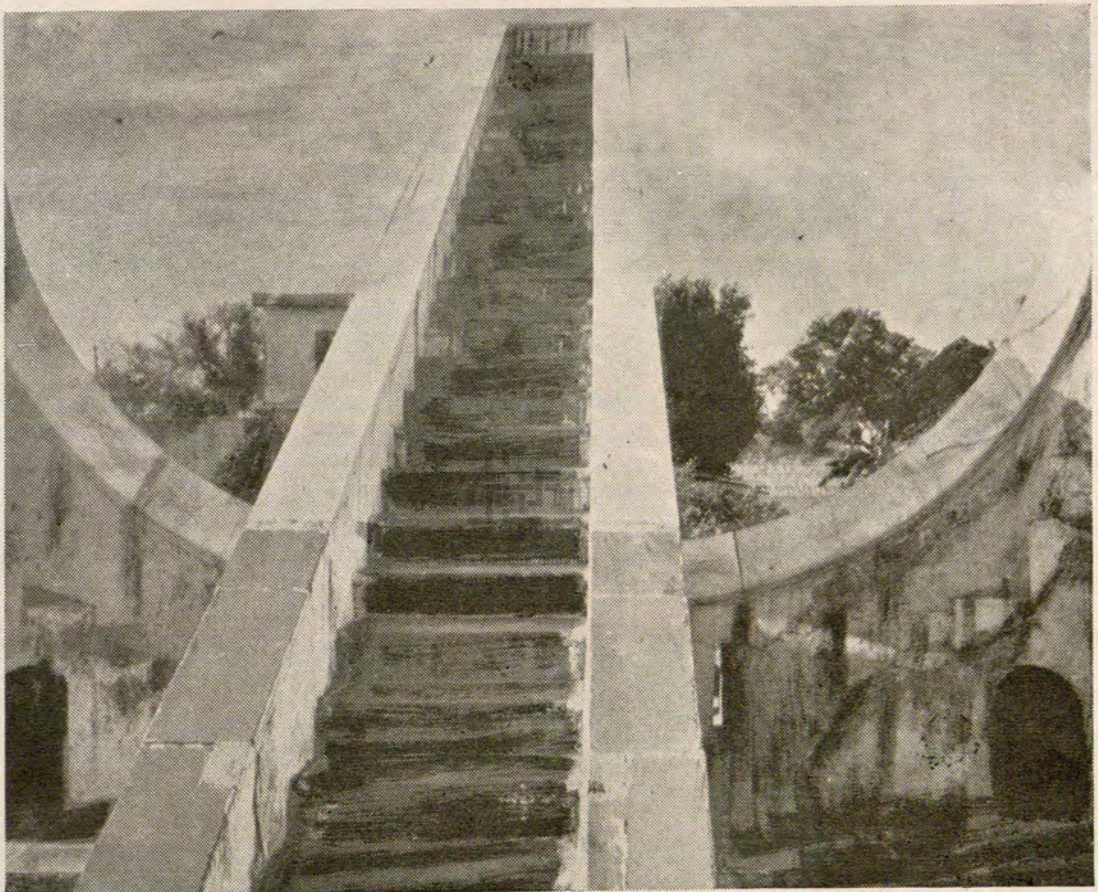


Pl. 7 Bṛhat Samrāṭ Yantra : Delhi

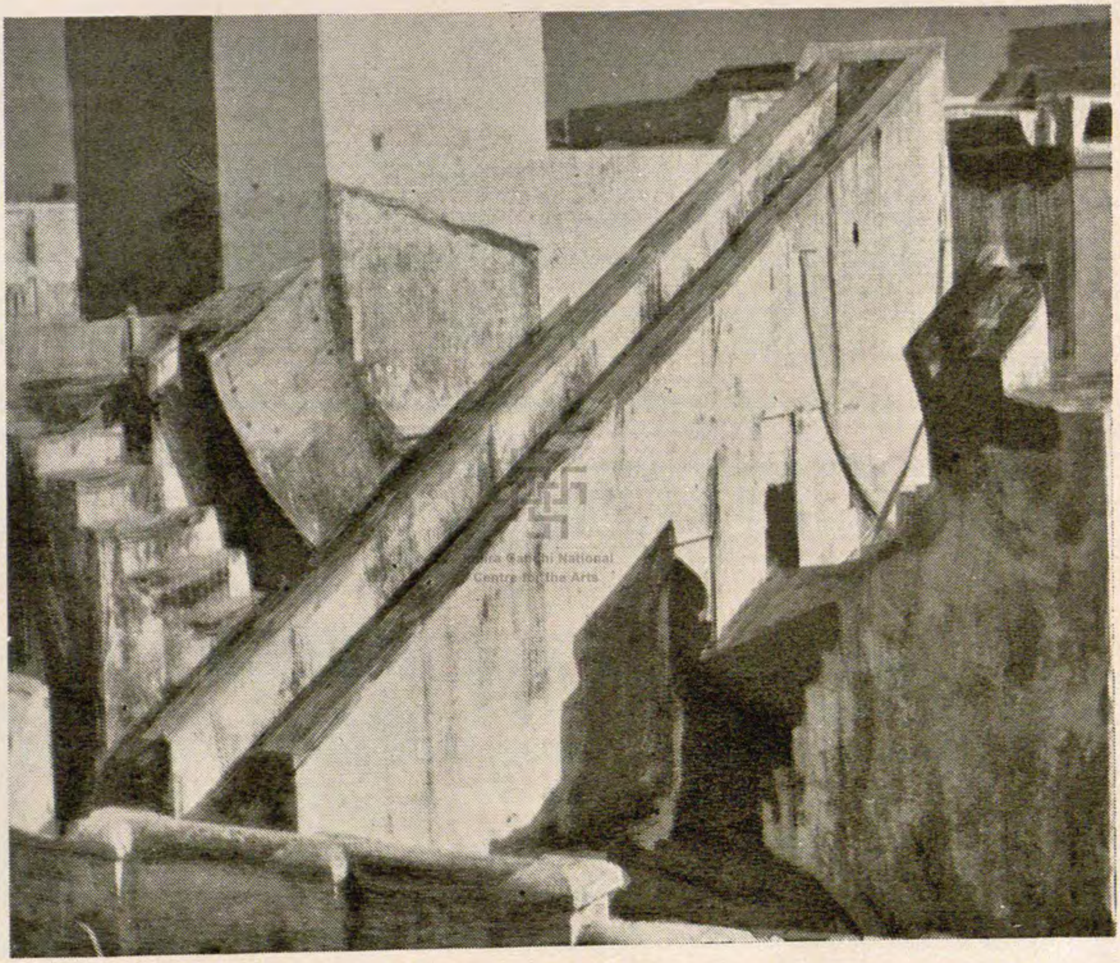
Pl. 8 The Gnomon of Bṛhat Samrāṭ Yantra : Delhi



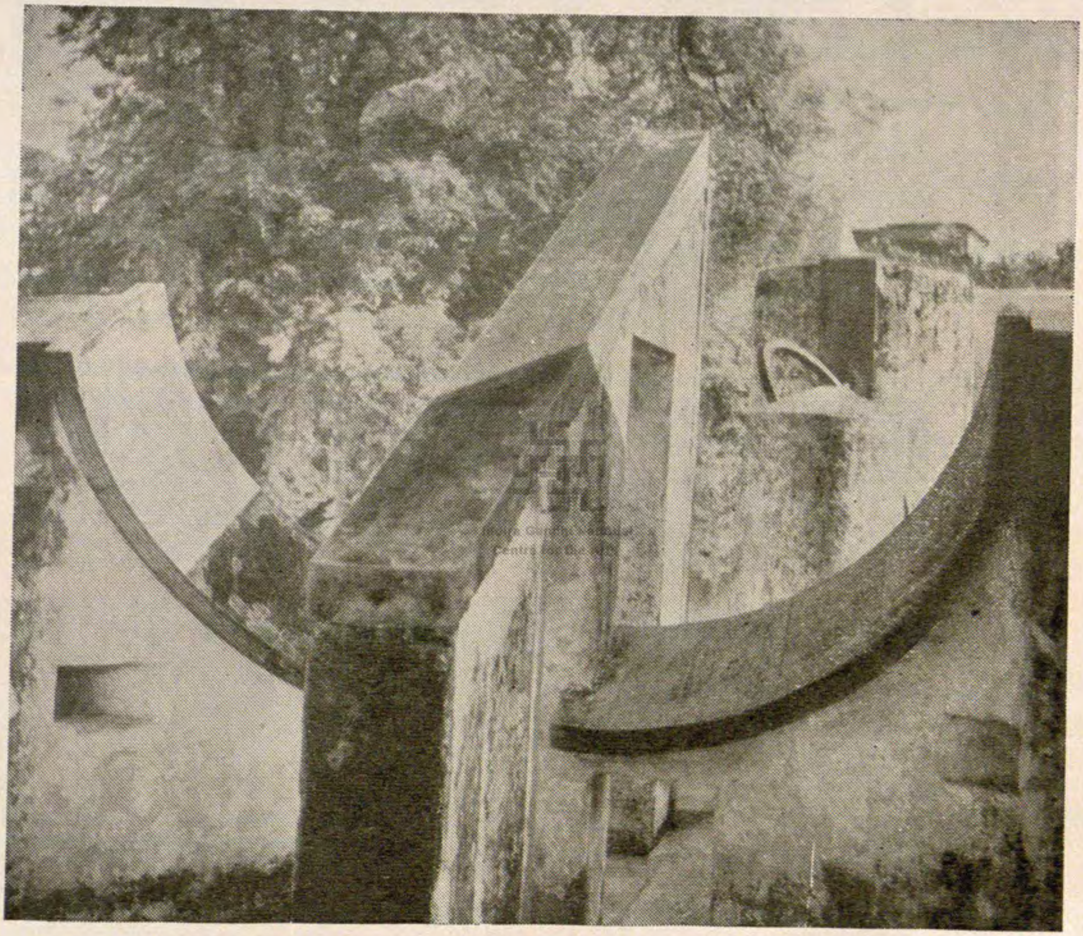
Pl. 9 Samrāṭ Yantra : Ujjain



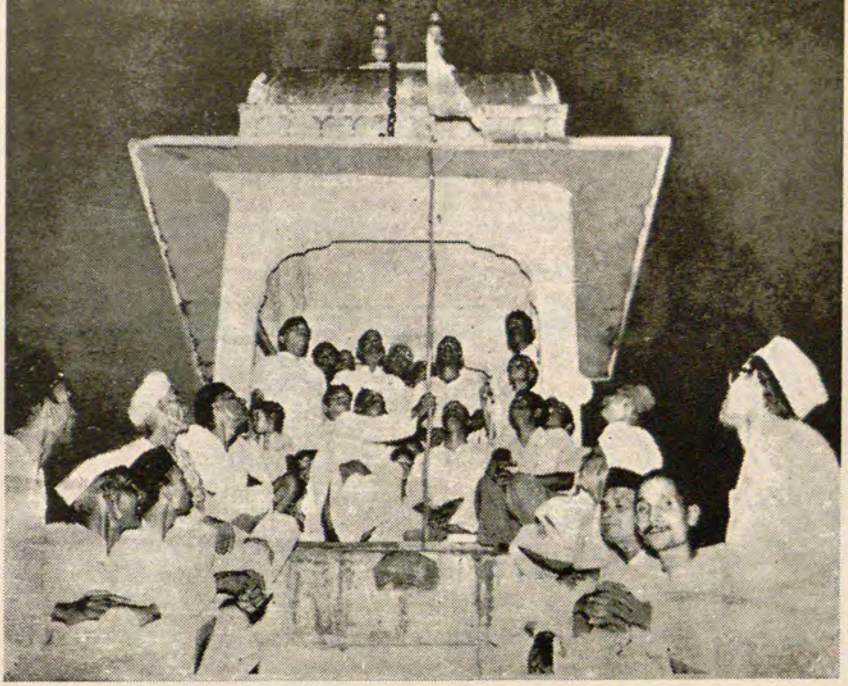
Pl. 10 The Gnomon of Samrāṭ Yantra : Ujjain



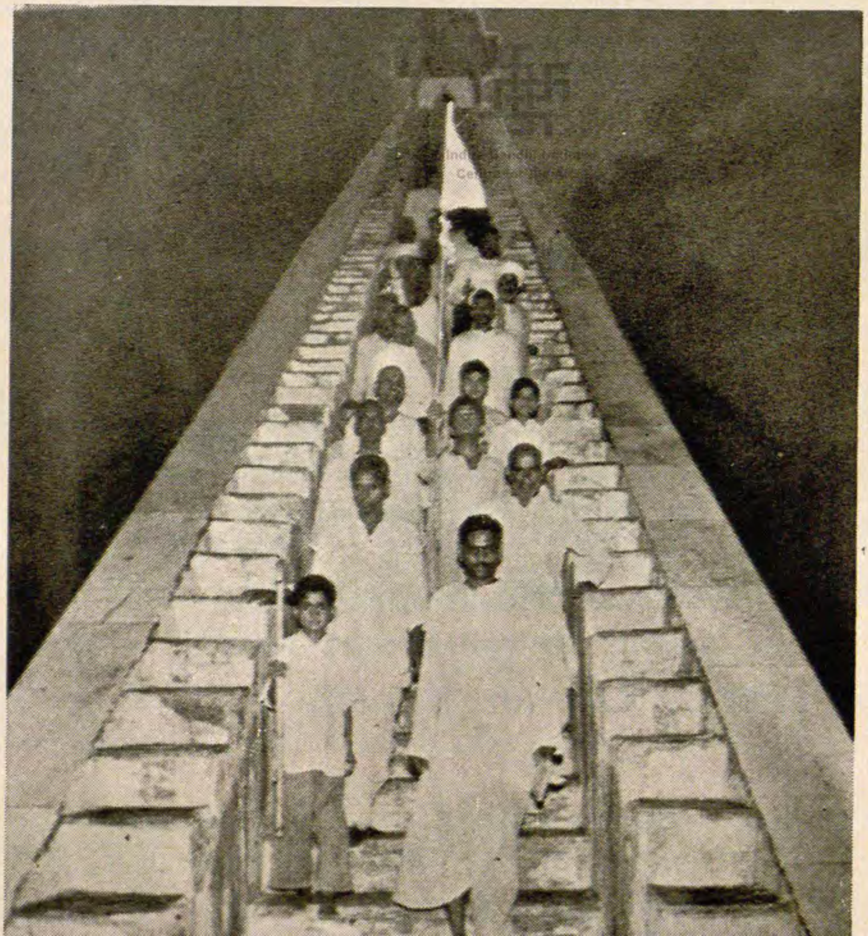
Pl. 11 Bṛhat Samrāṭ Yantra : Varanasi



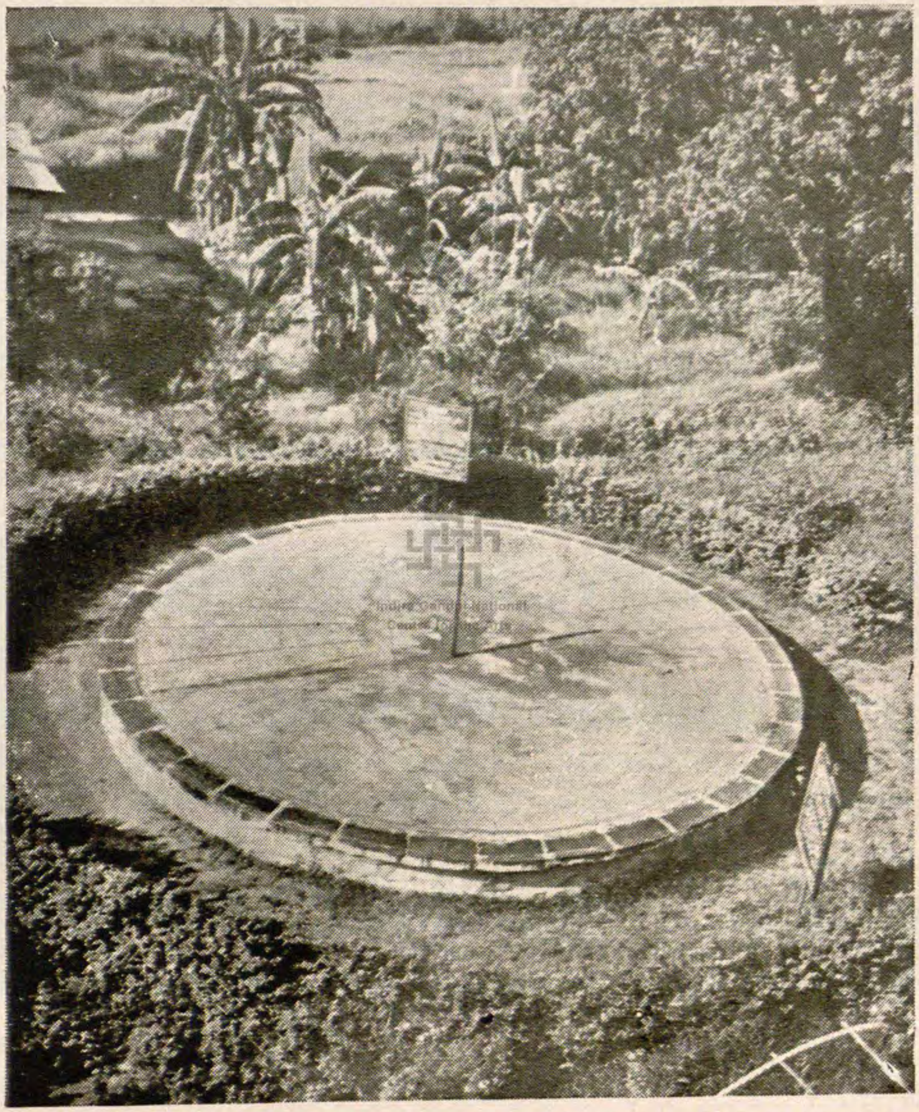
Pl. 12 Laghu Samrāṭ Yantra : Varanasi



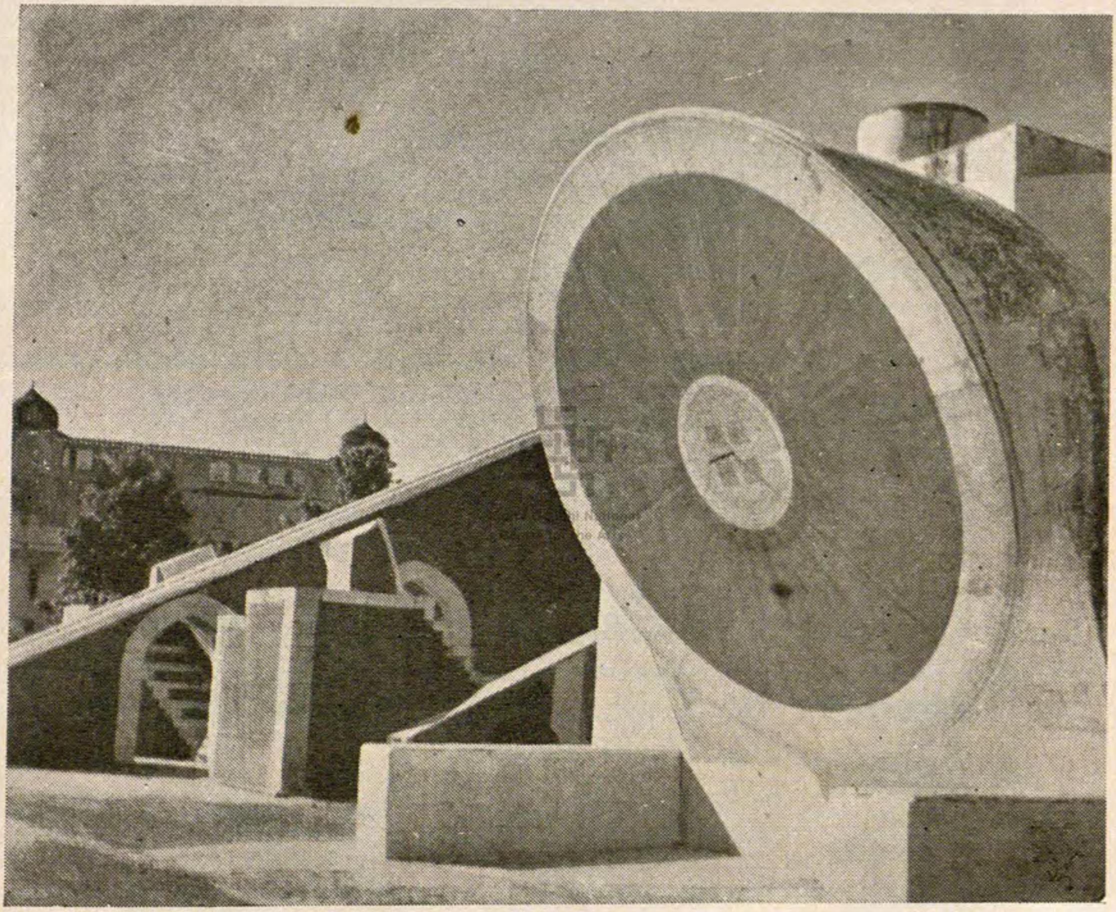
Pl. 13 The 'Pavana–Dhāraṇa' Cerem ony on the 'Chatrī' of the Bṛhat Samrāṭ Yantra : Jaipur



Pl. 14 Pandit Kalyan Datt Sharma, 'Jyotiśā cārya' former Supervisor, Jaipur Observatory, leading the procession of astronomers on the gnomon of the Bṛhat Samrāṭ Yantra after the 'Pavana Dhāraṇa' Ceremony.

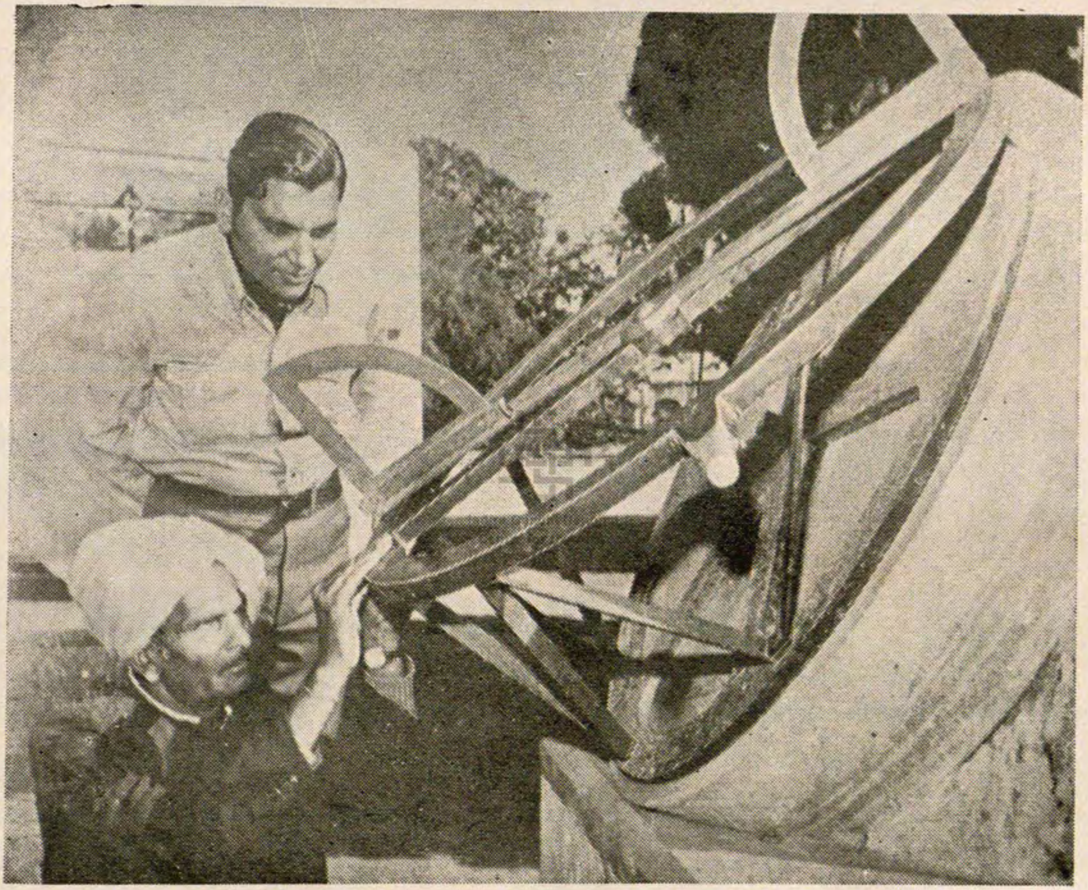


Pl: 15 Śaṅku Yantra : Ujjain



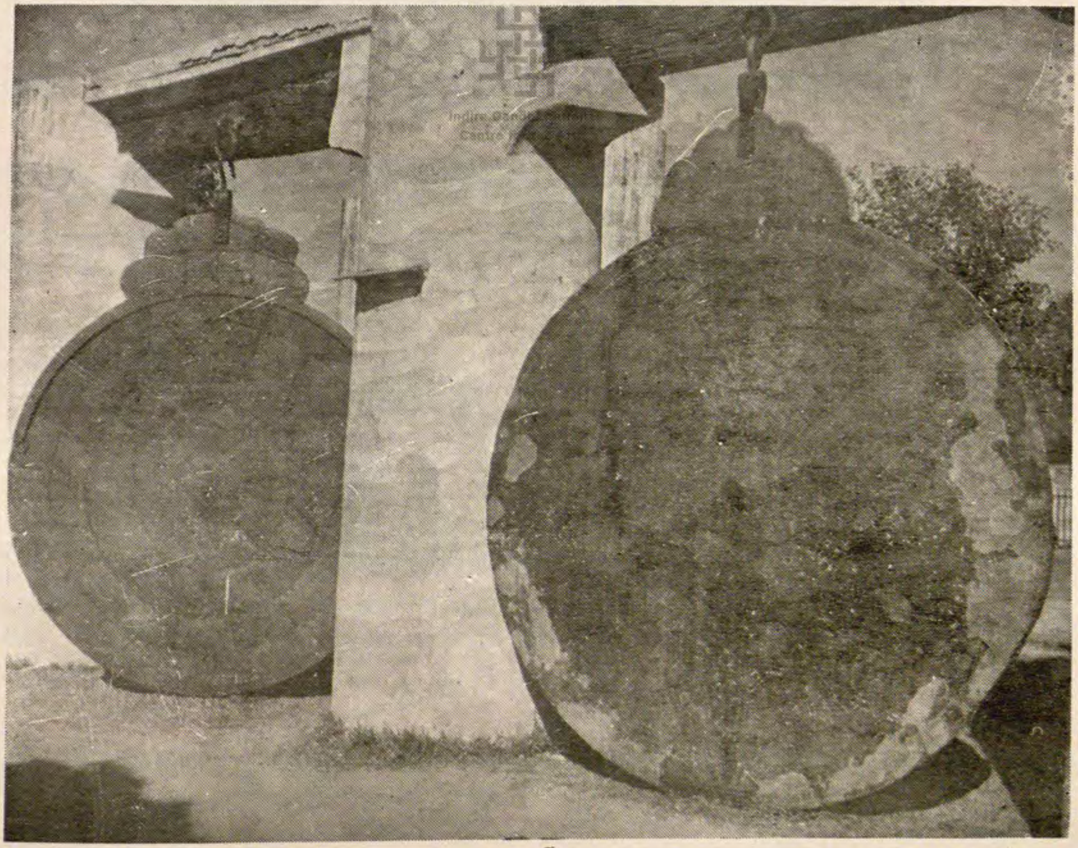
Pl. 16 Nārivalaya Yantra : Jaipur

Pl. 18 Nārivalaya Yantra : Varanasi

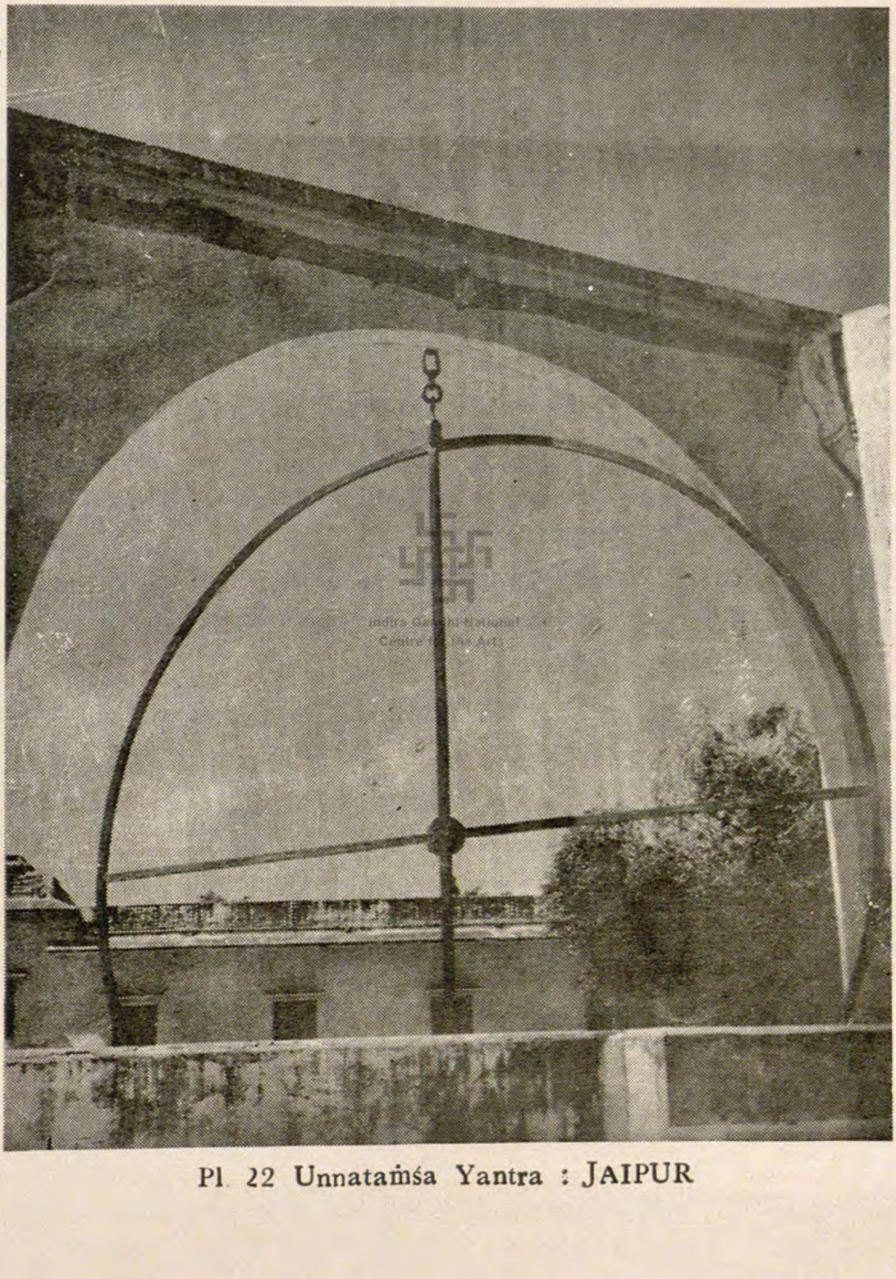


Pl. 19 Krāntivṛtta Yantra with attachment : JAIPUR

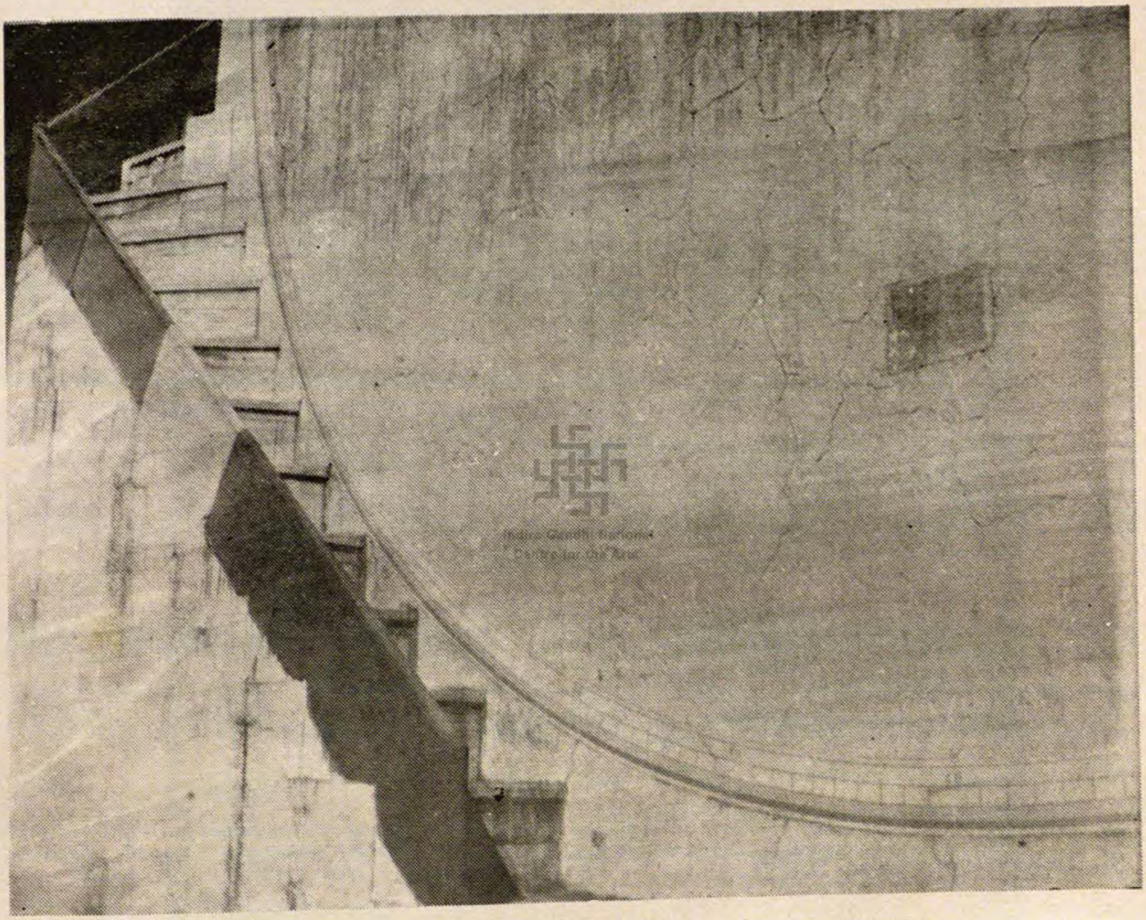
Pl. 20 Models of Yantra Rāja (Astrolabe) : JAIPUR



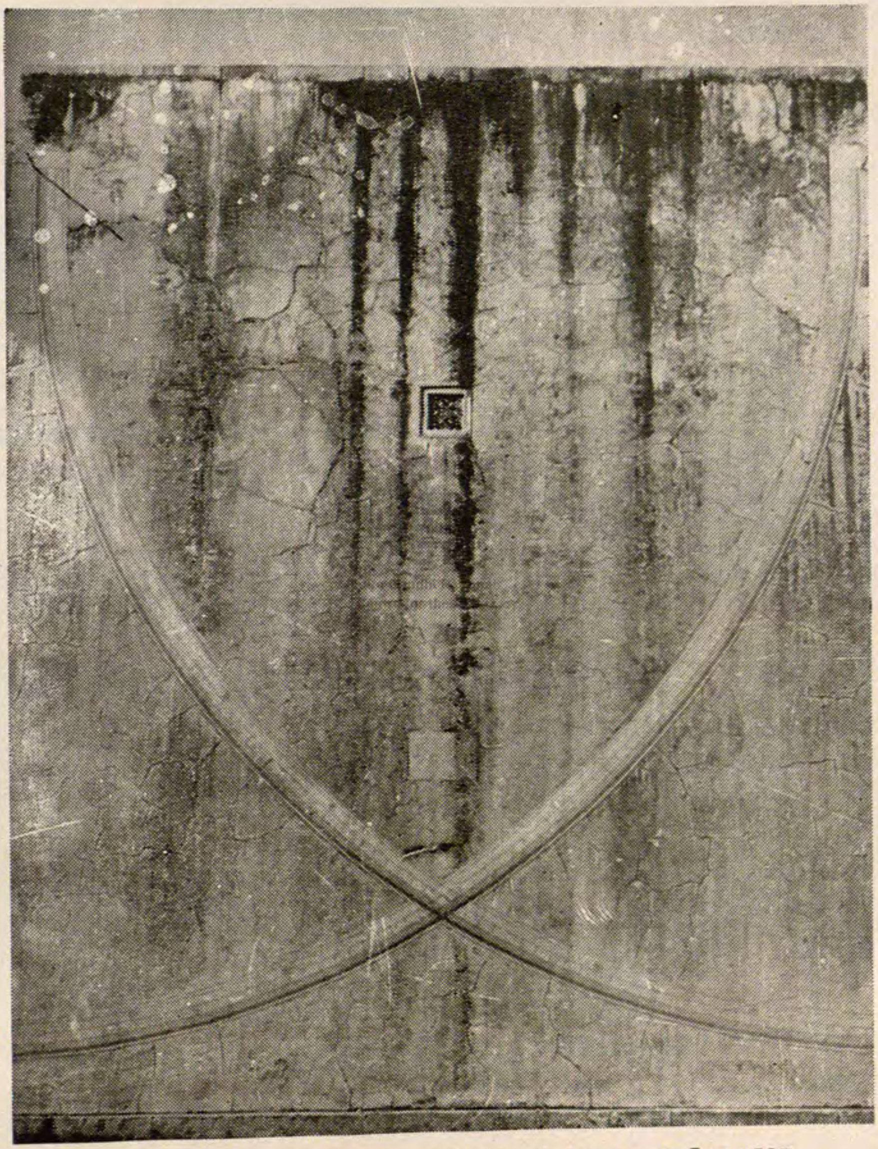
Pl. 21 Yantra Rāja : JAIPUR



Pl. 22 Unnataṁśa Yantra : JAIPUR

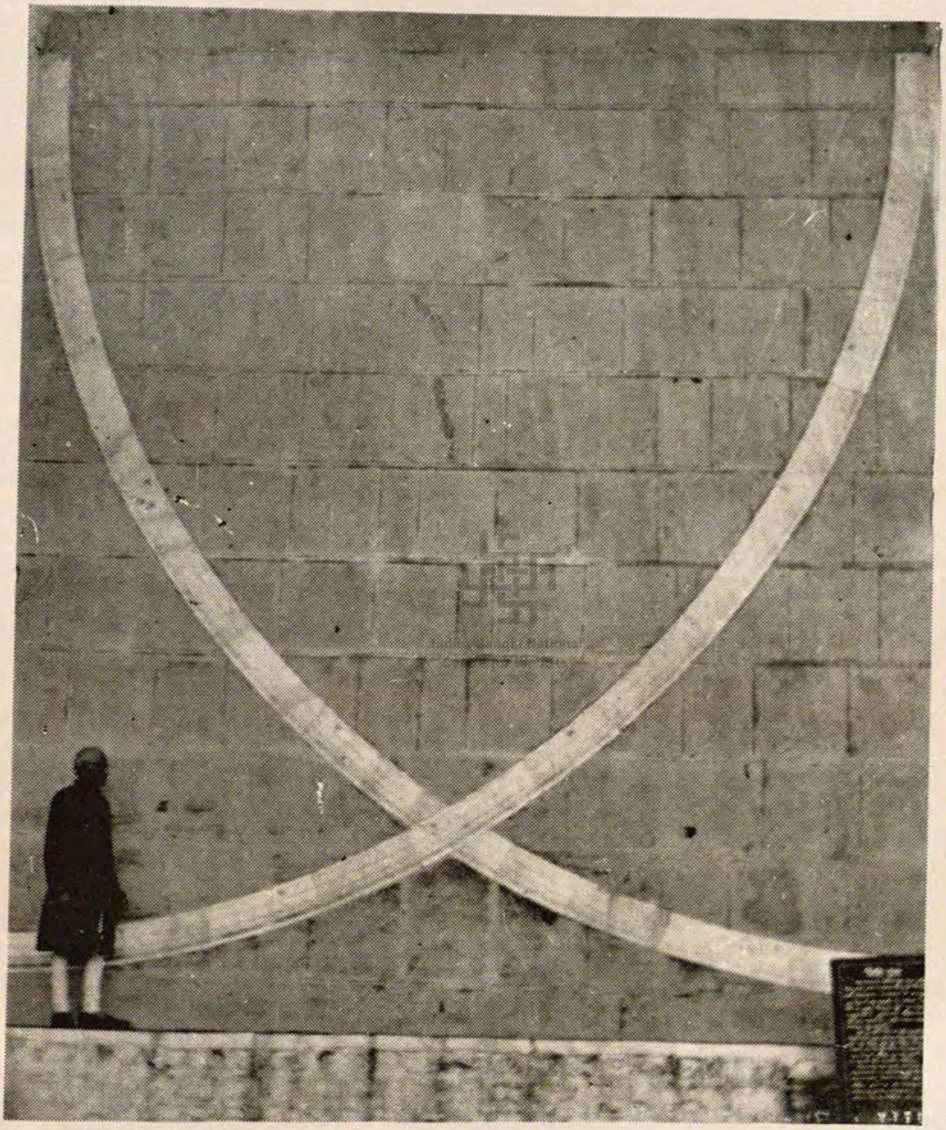


Pl. 23 Western Dakṣiṇovṛtti Bhitti Yantra : JAIPUR

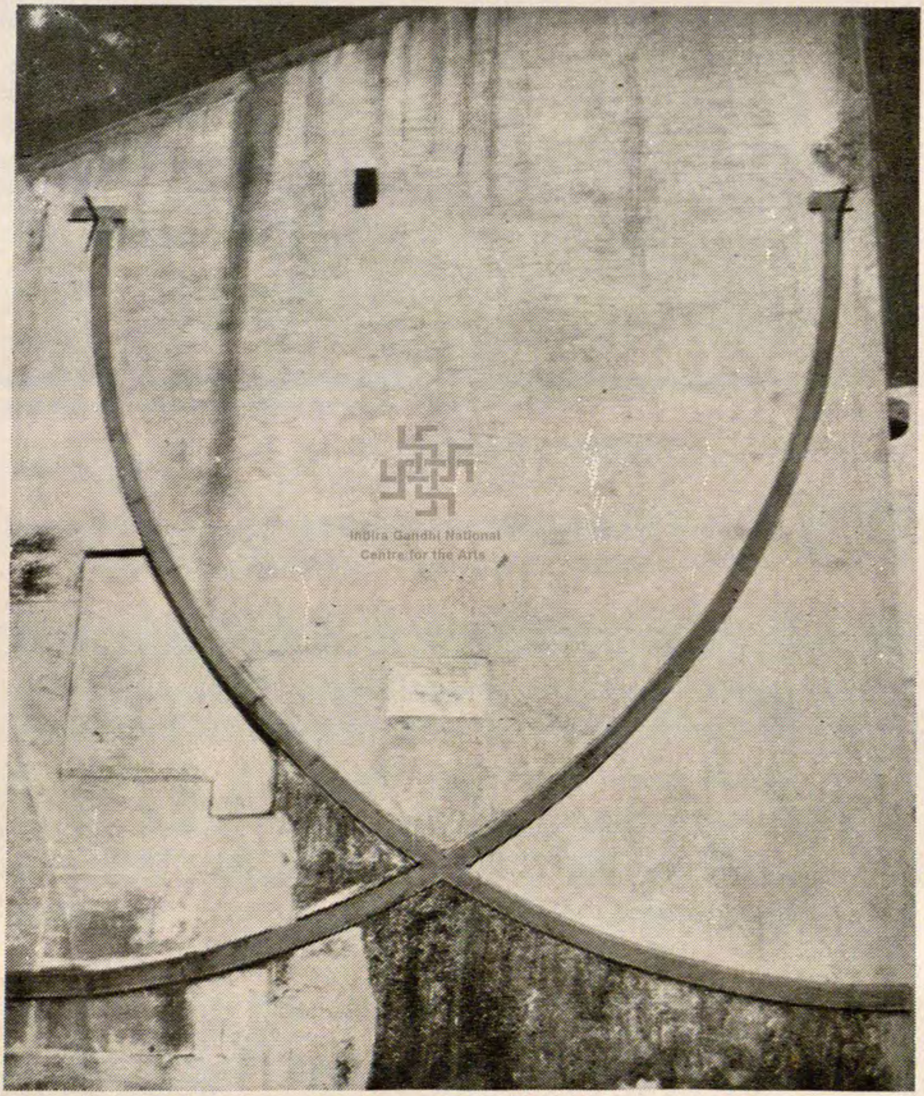


Pl. 24 Eastern Dakṣiṇovṛtti Bhitti Yantra : JAIPUR

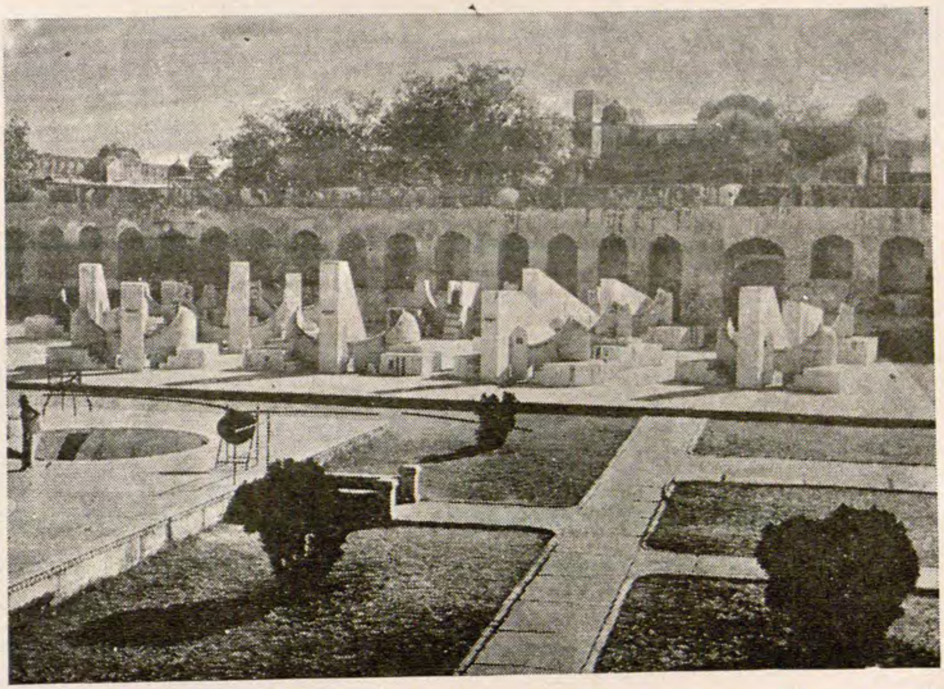
Pl. 25 Bhitti Yantra : DELHI



Pl. 26 Pandit Kamalakant Joshi at the Dakṣṇovṛtti Bhitti Yantra (E) : UJJAIN



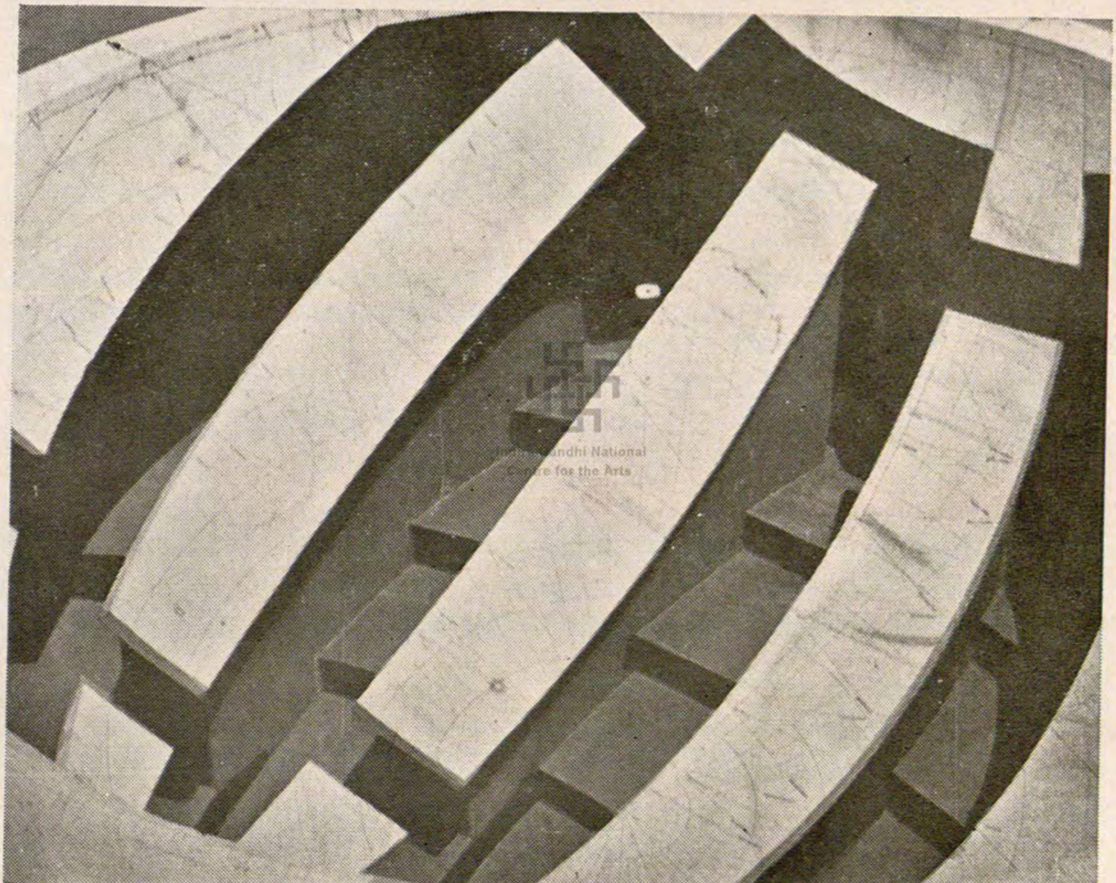
Pl. 27 Dakṣiṇovṛtti Bhitti Yantra (E) : VARANASI



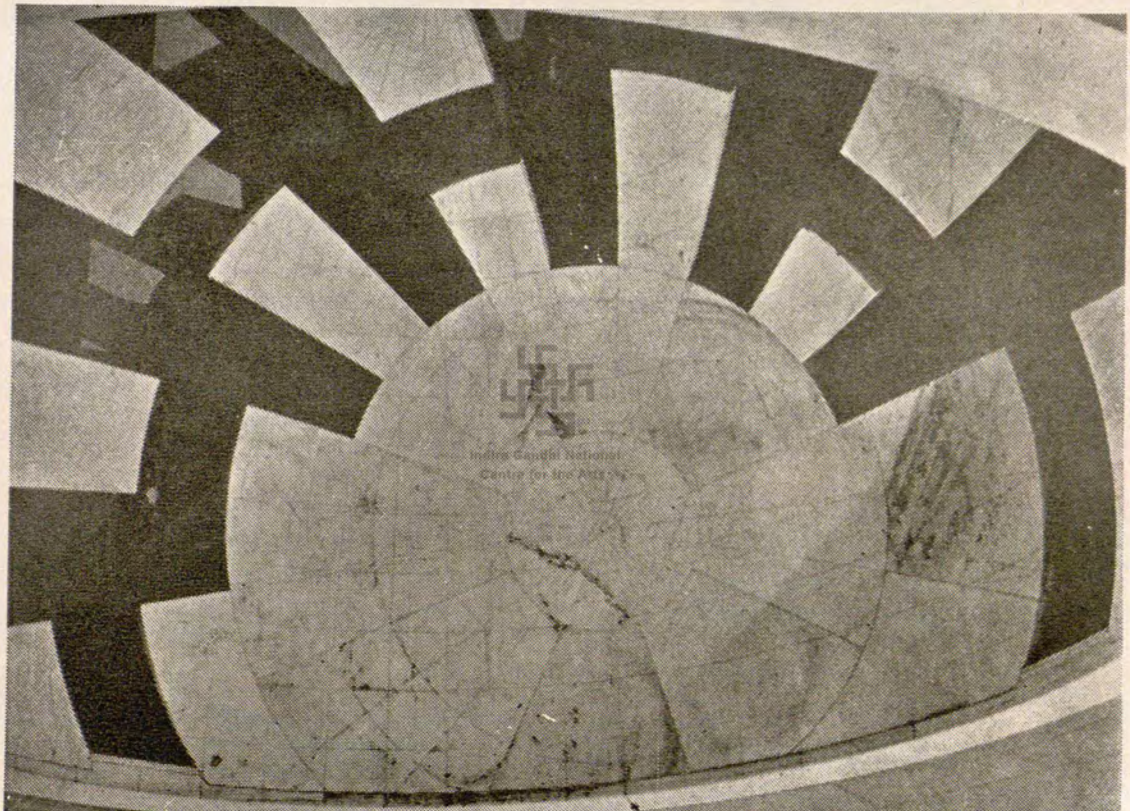
Pl. 28 Rāśivālaya : JAIPUR

Pl. 29 Rāśi Yantras : JAIPUR

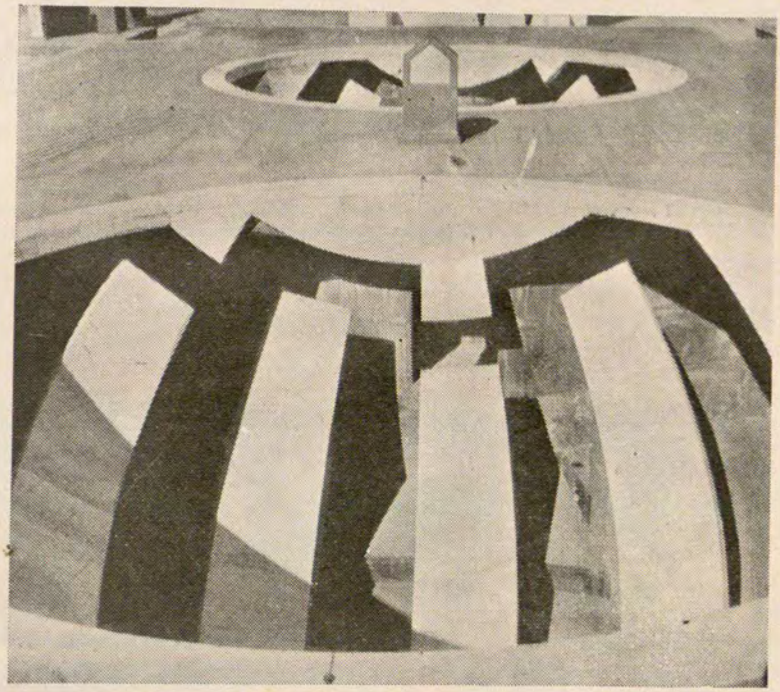
pl. 30 Jai Prakāśa Yantra : JAIPUR



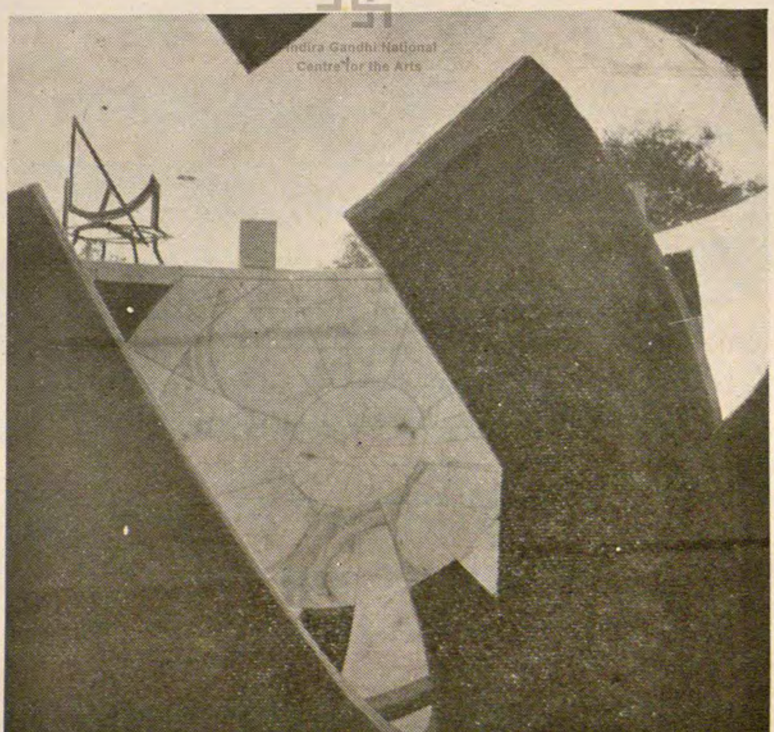
Pl. 31 Graduated Sectors Jai Prakāśa Yantra : JAIPUR



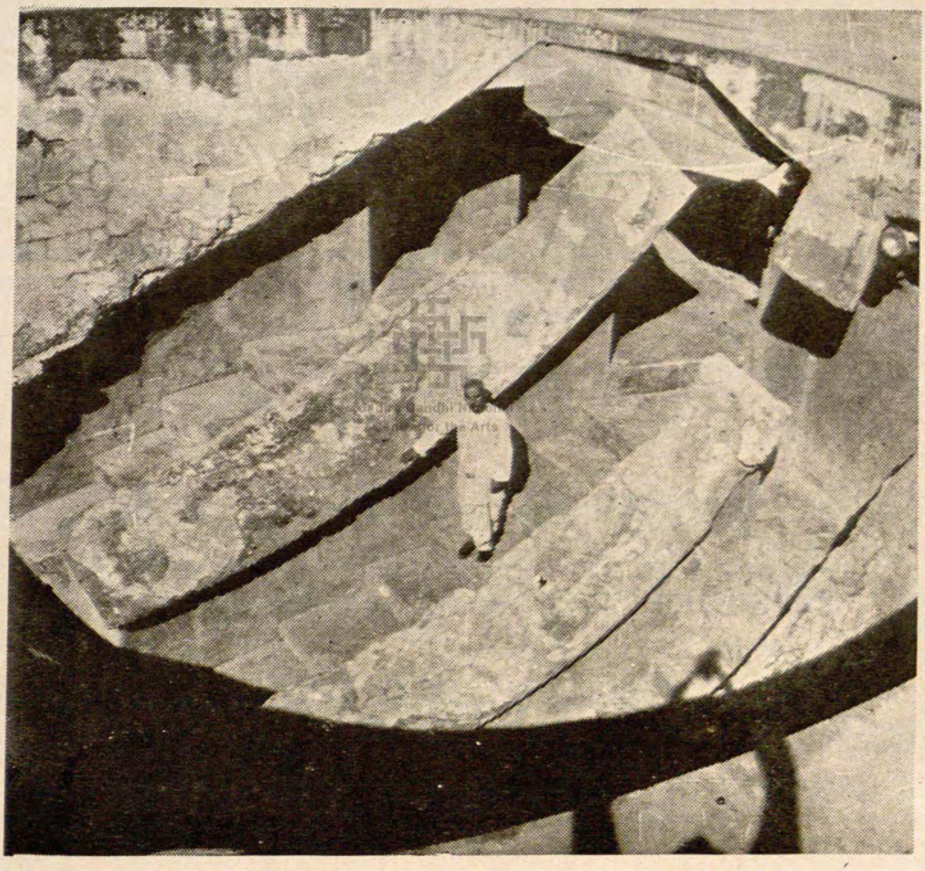
Pl. 32 Graduated Interior—Jai Prakāśa Yantra : JAIPUR



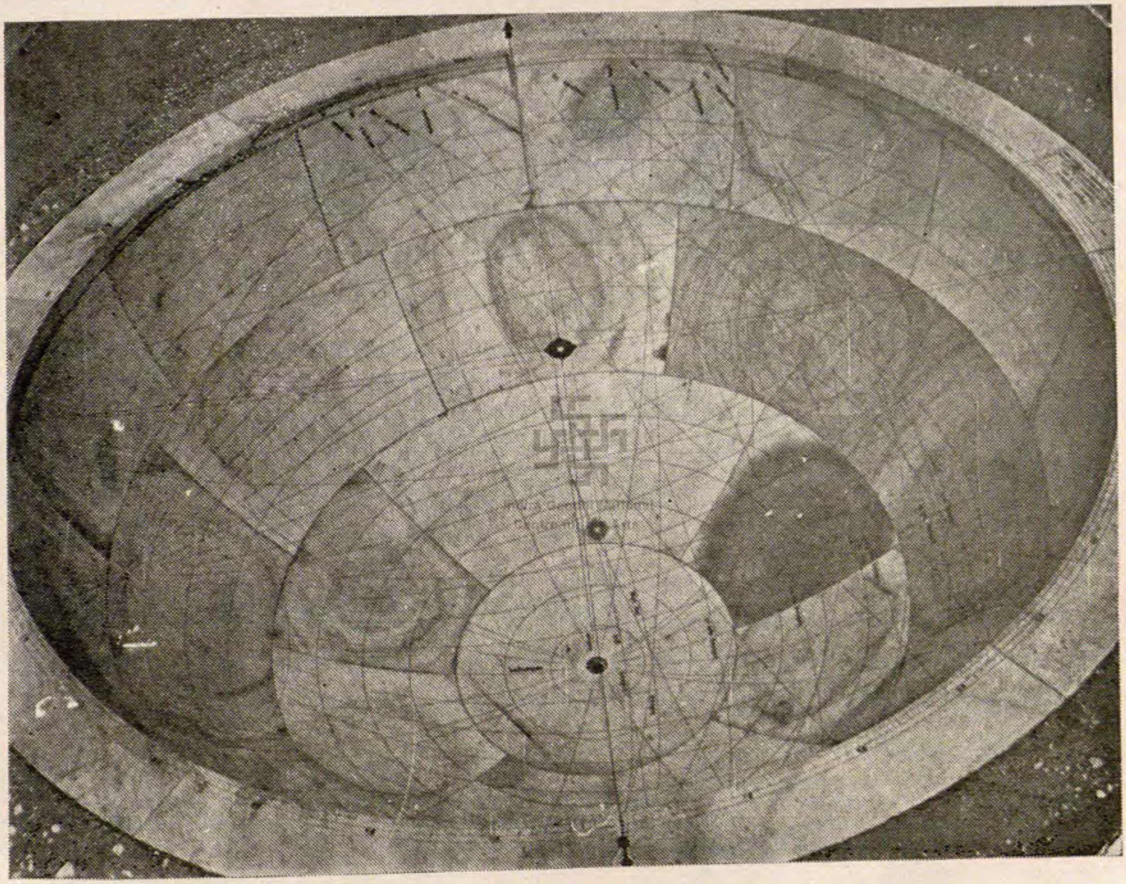
Pl. 33 Interior—Jai Prakāśa Yantra : JAIPUR



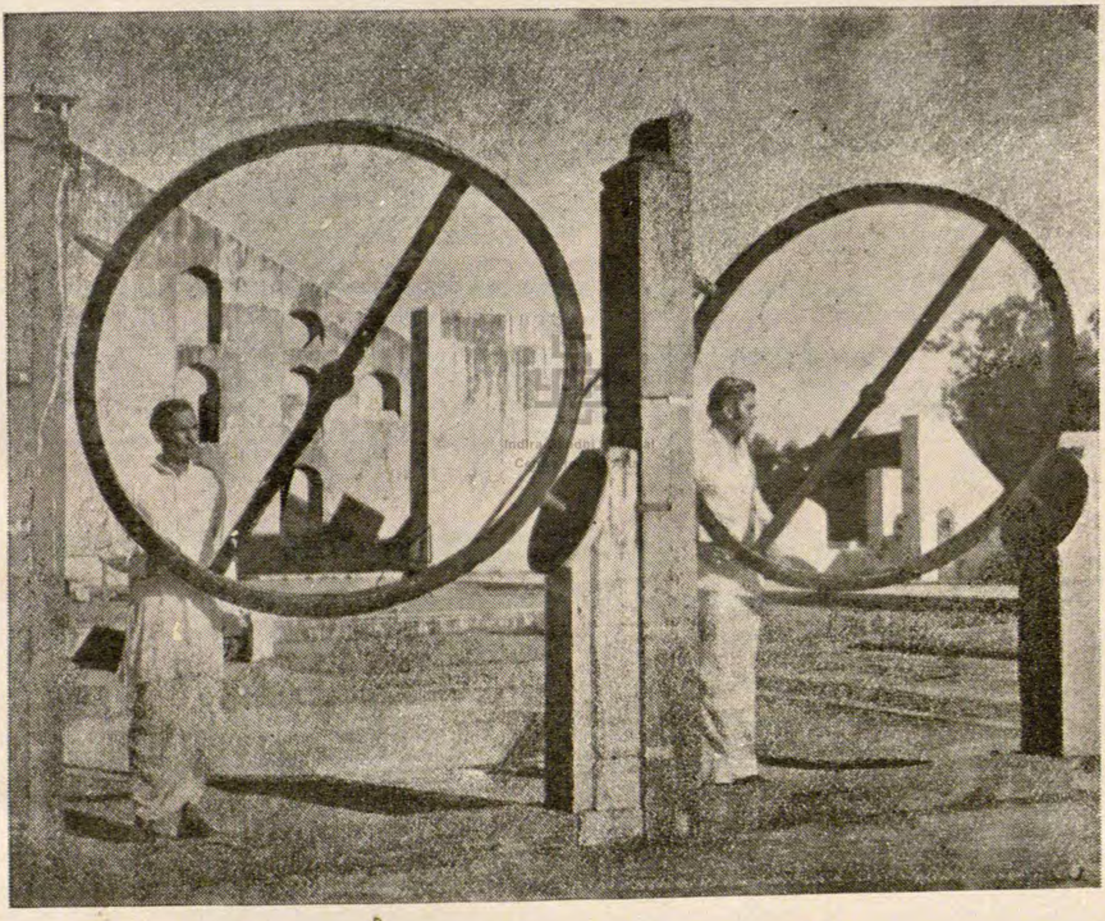
Pl. 34 Interior View of Jai Prakāśa Yantra : JAIPUR



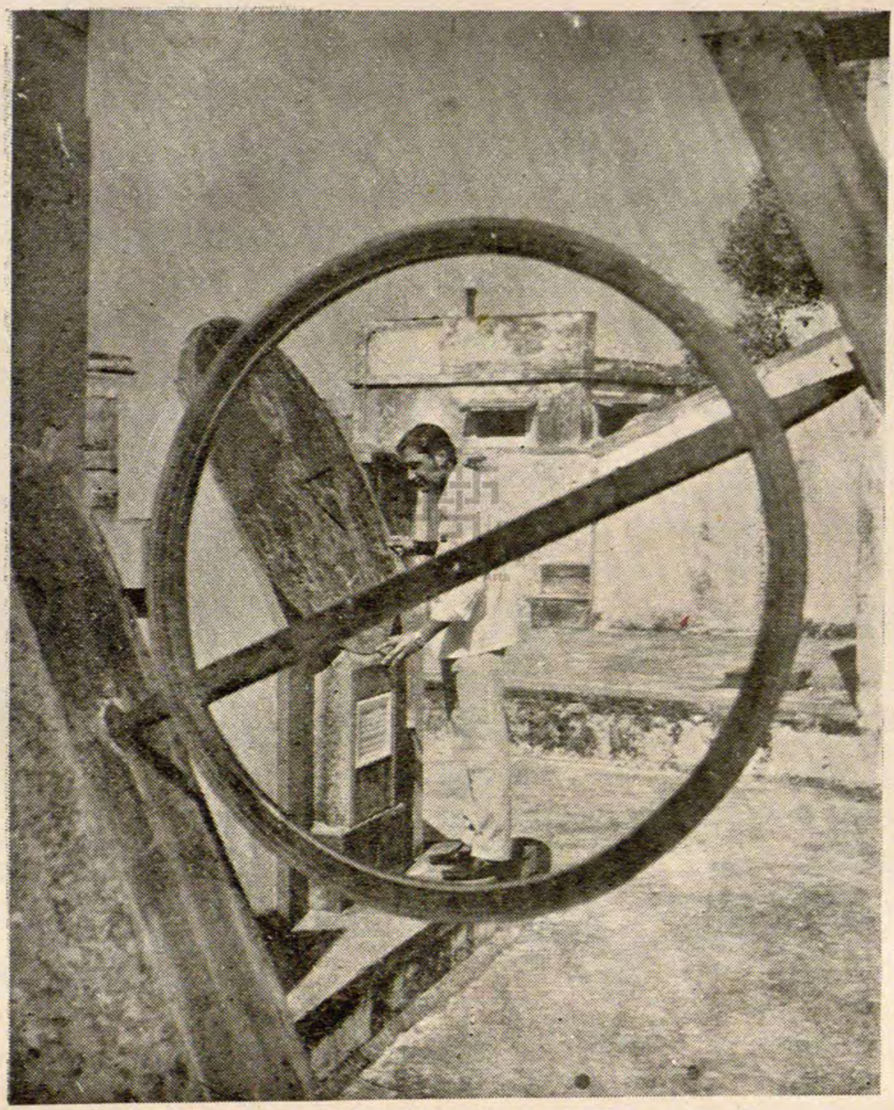
Pl. 35 Jai Prakāśa Yantra [redacted] *Delhi*.



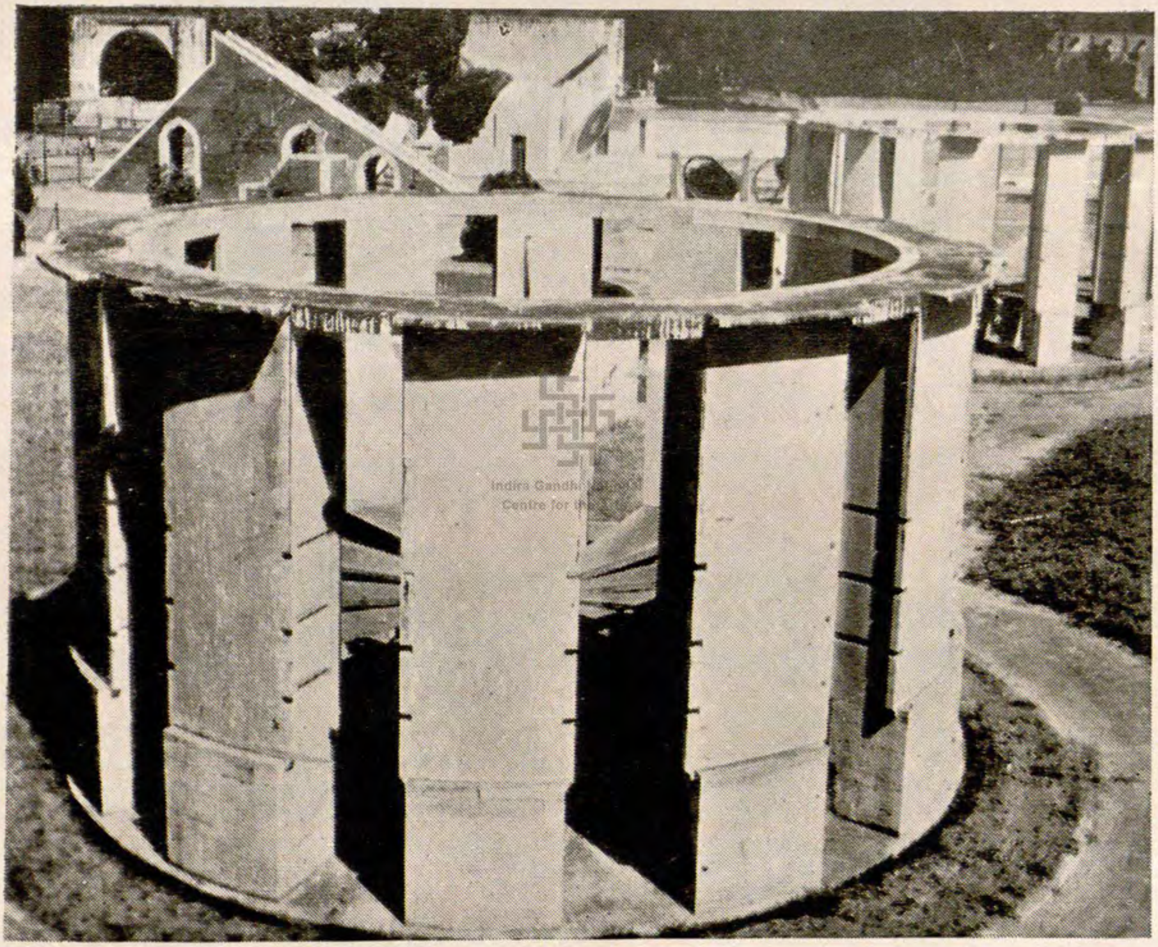
Pl. 36 Graduated Interior—Kapāli Yantra : JAIPUR



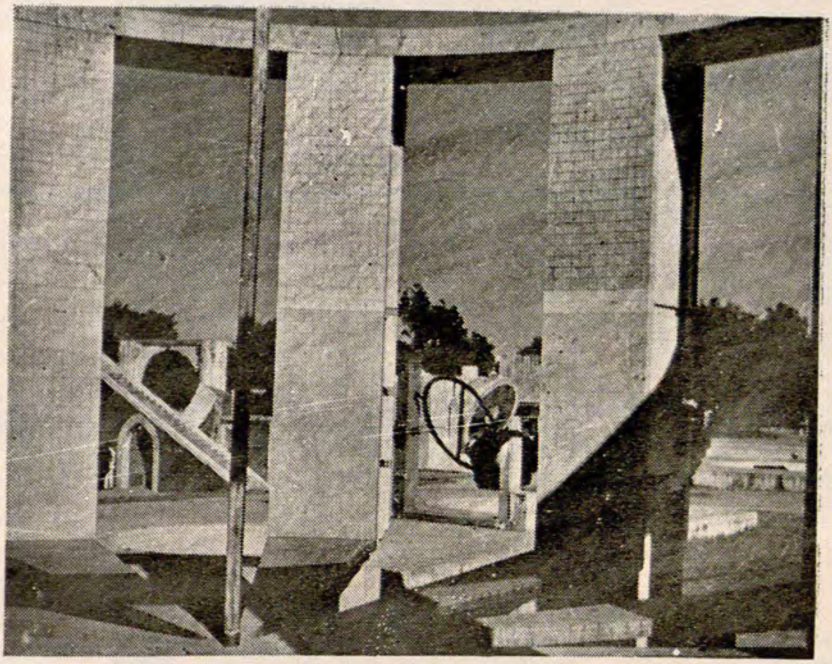
Pl. 37 Declination Instruments : JAIPUR



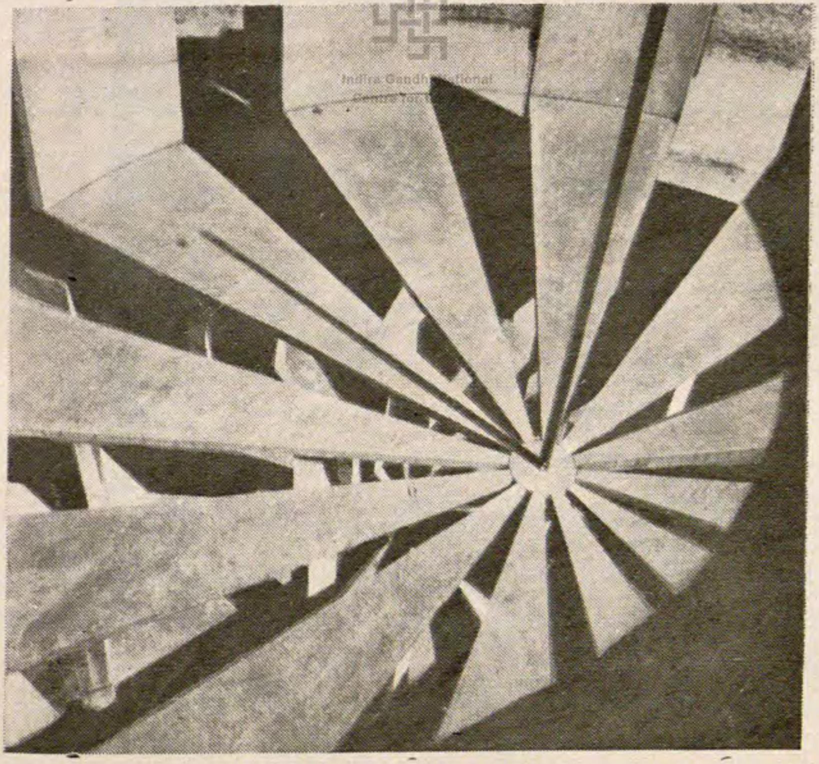
Pl. 38 Cakra Yantra : Varanasi



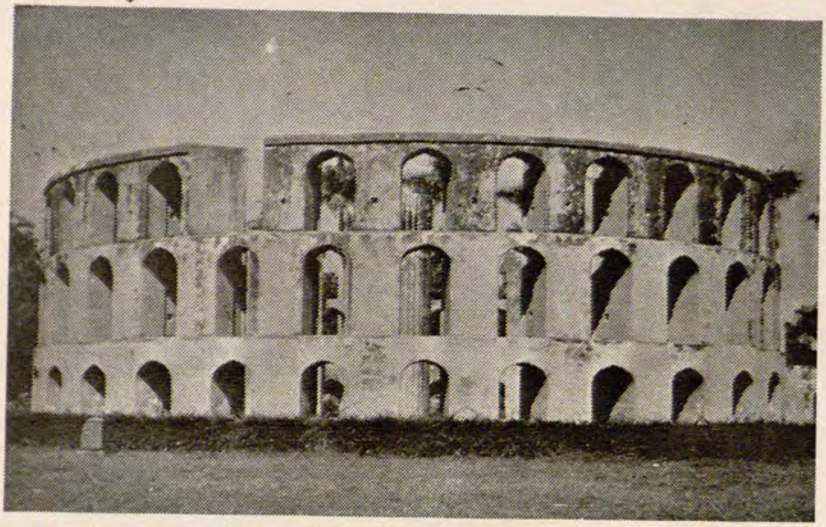
Pl. 39 Rāma Yantras : Jaipur



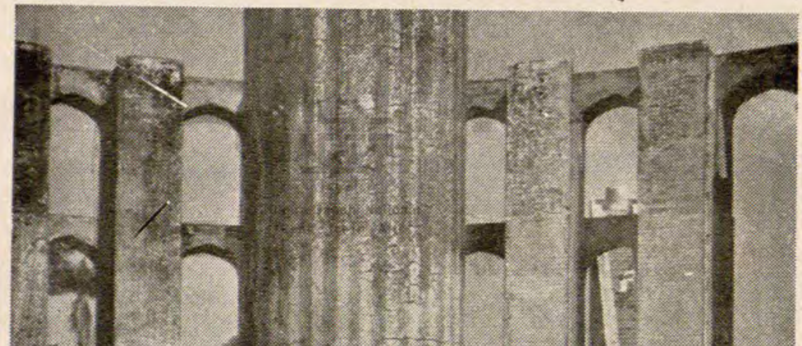
Pl. 40 Graduated Interior--Rāma Yantra : Jaipur



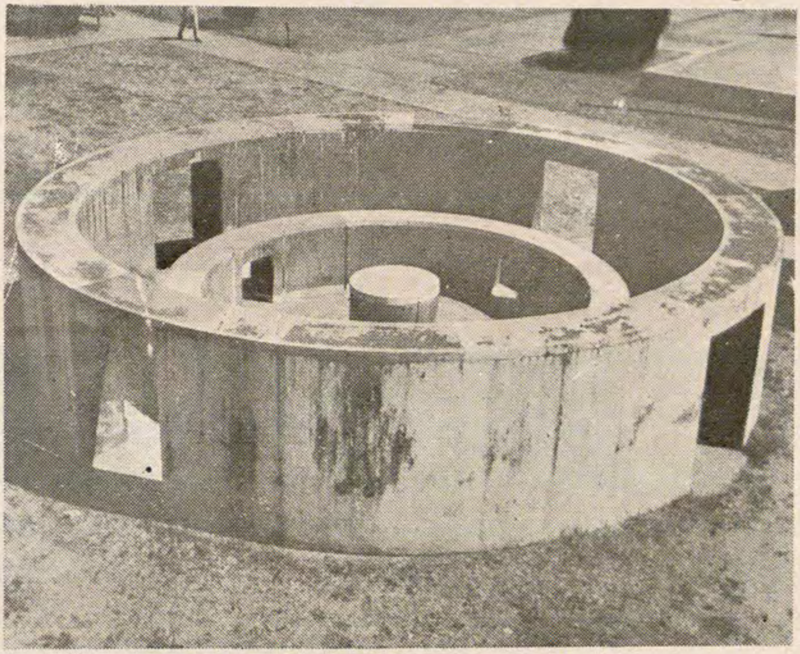
Pl. 41 Interior--Rāma Yantra : Jaipur



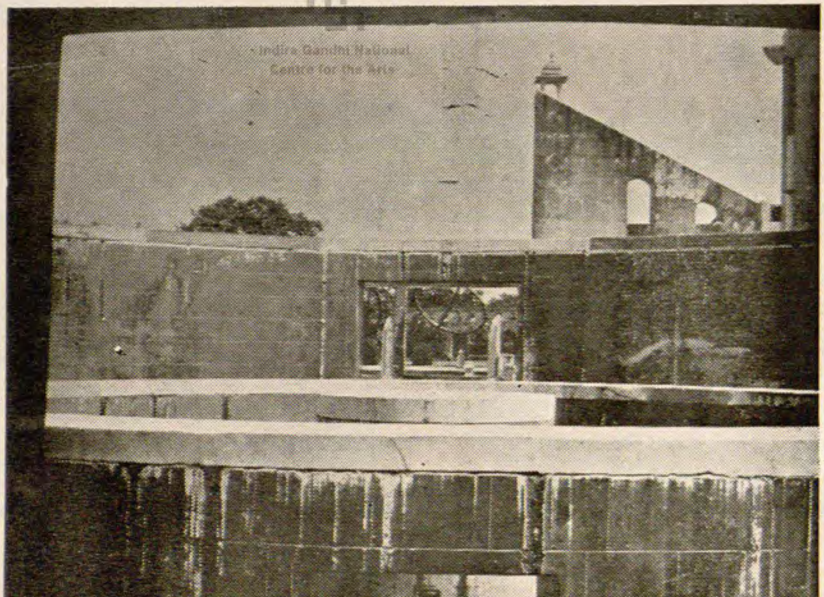
Pl. 42 Rāma Yantra : Delhi



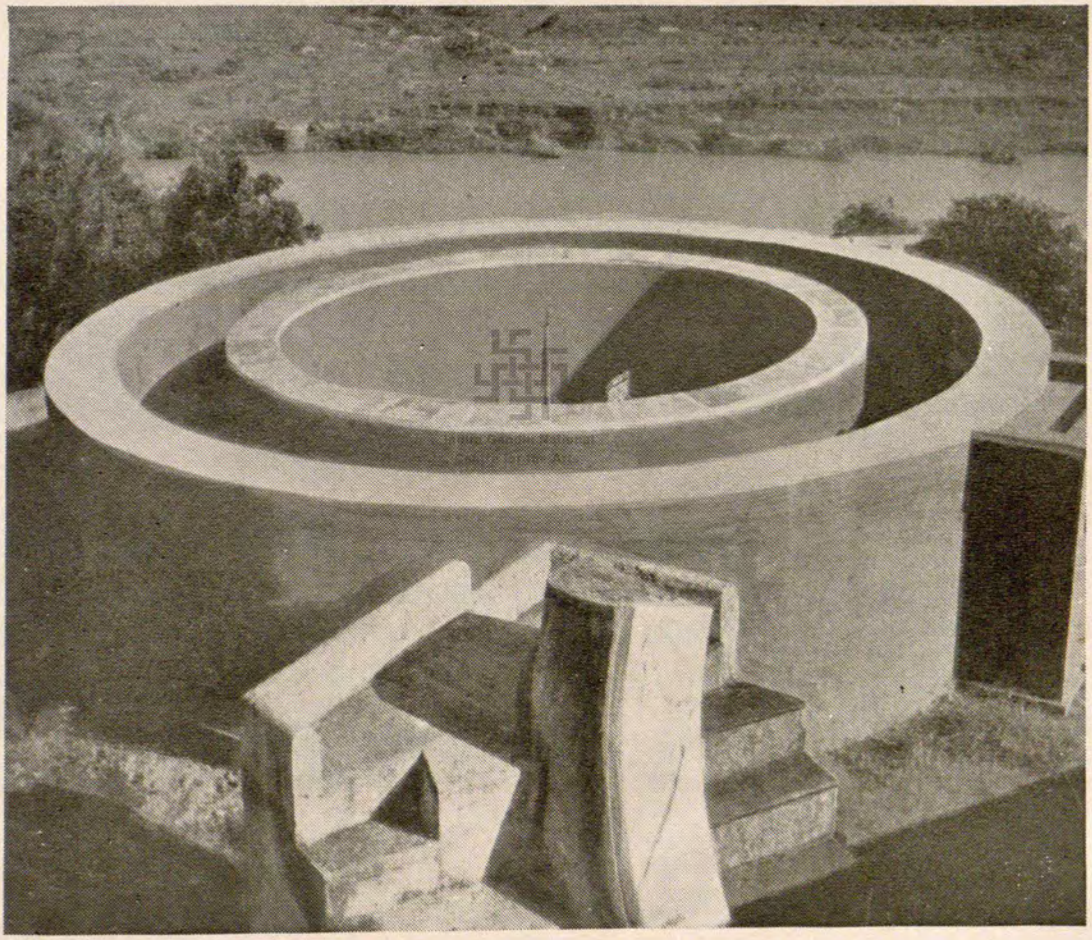
Pl. 43 Interior View of Rāma Yantra : Delhi



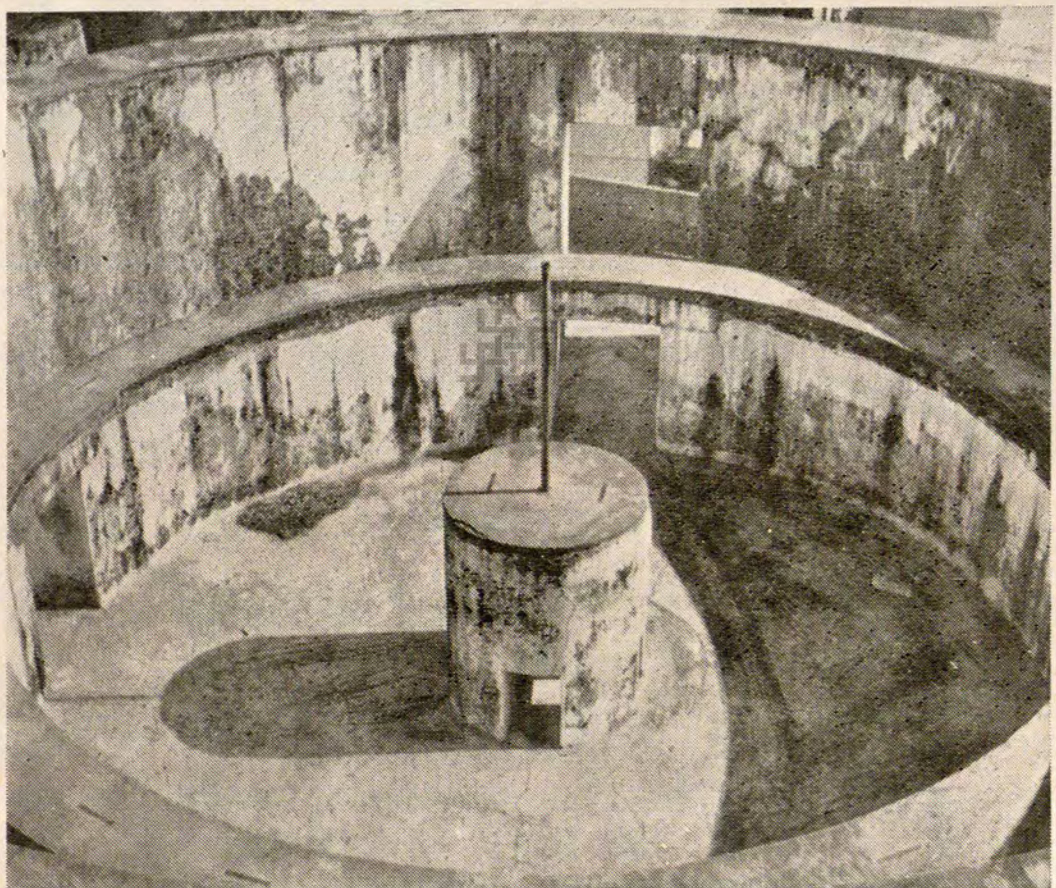
Pl. 44 Digaṁśa Yantra : Jaipur



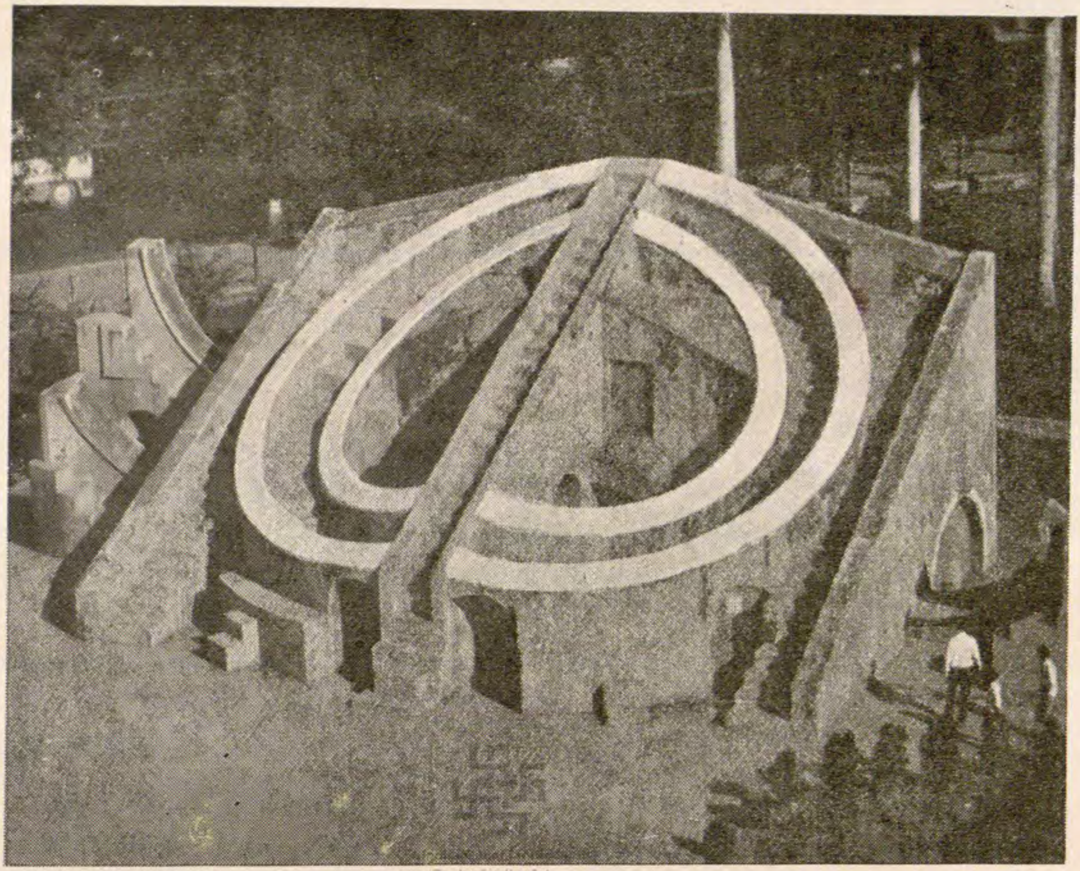
Pl. 45 Interior view of Digaṁśa Yantra : Jaipur



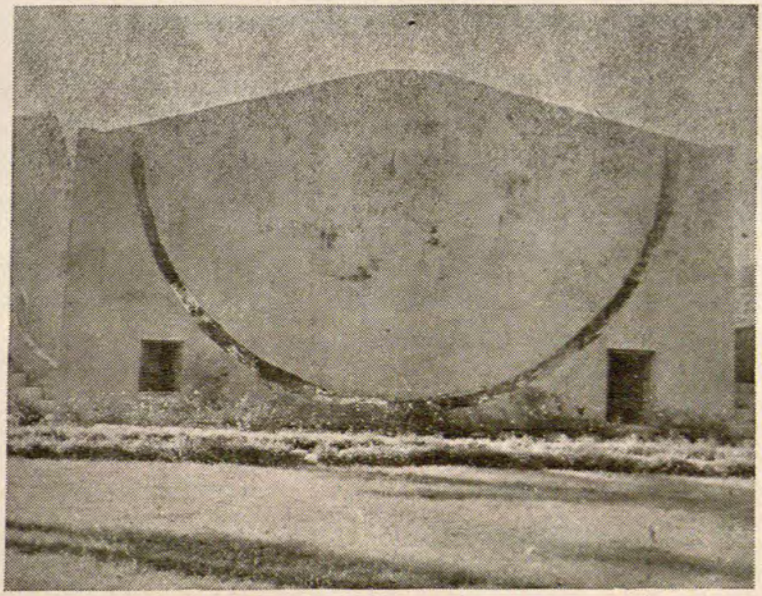
Pl. 46 Digaṁśa Yantra : Ujjain



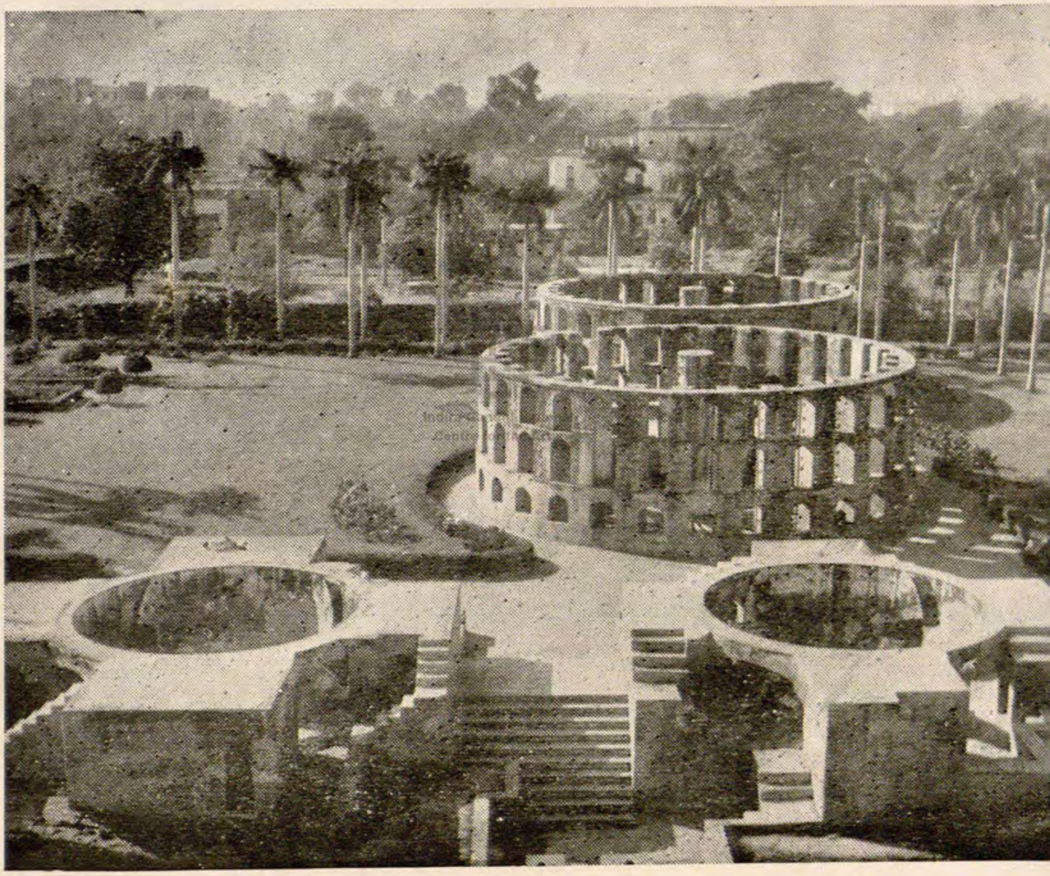
Pl. 47 Interior of Digaṃśa Yantra : Varanasi



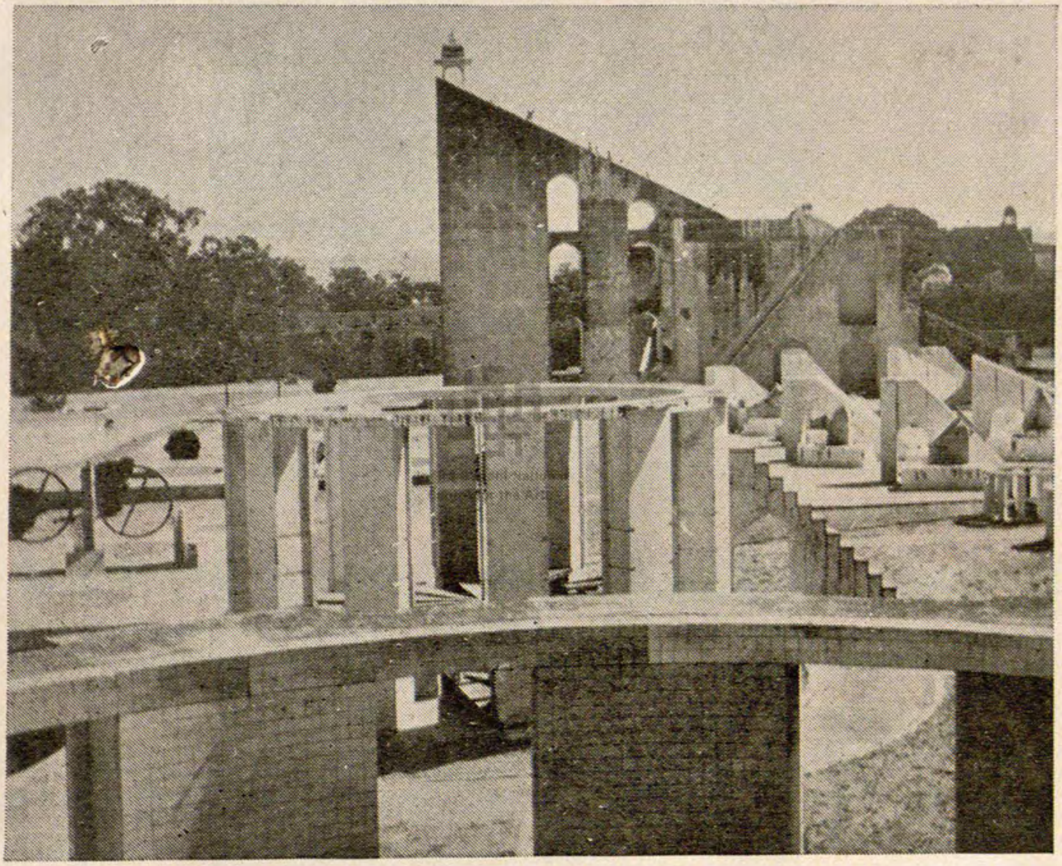
Pl. 48 Miśrā Yantra : Delhi



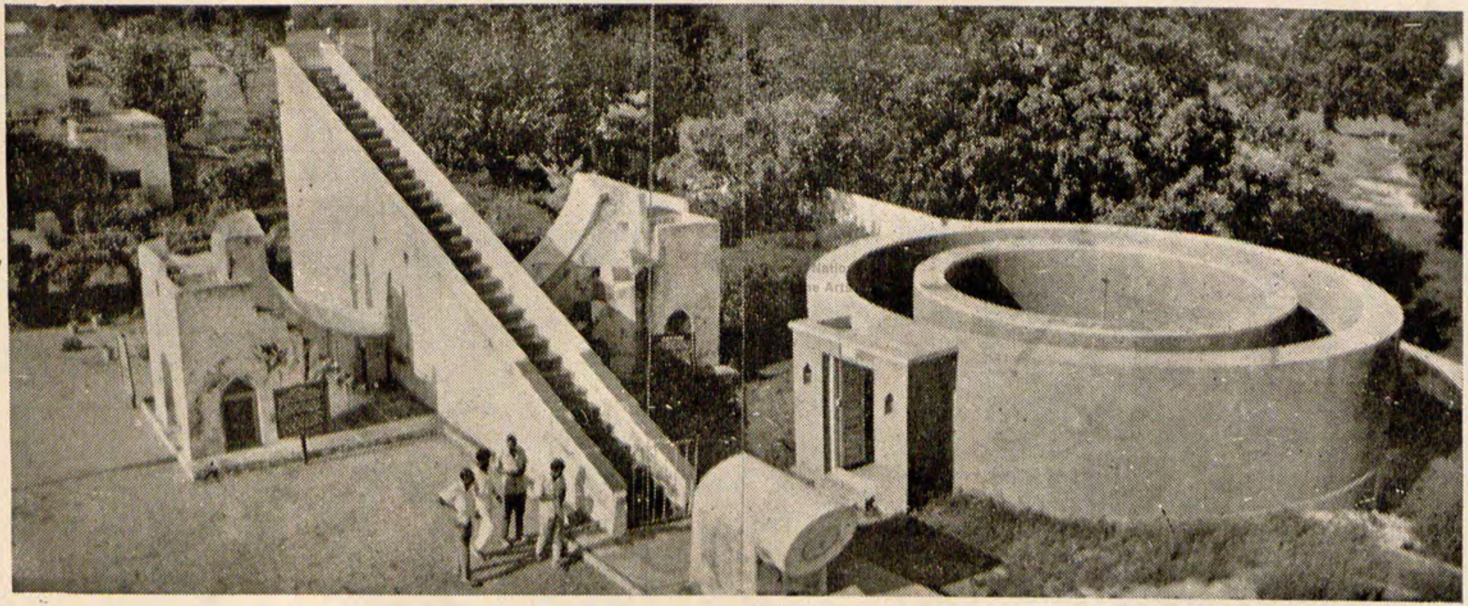
Pl. 49 Karka Rāśivālaya : Delhi



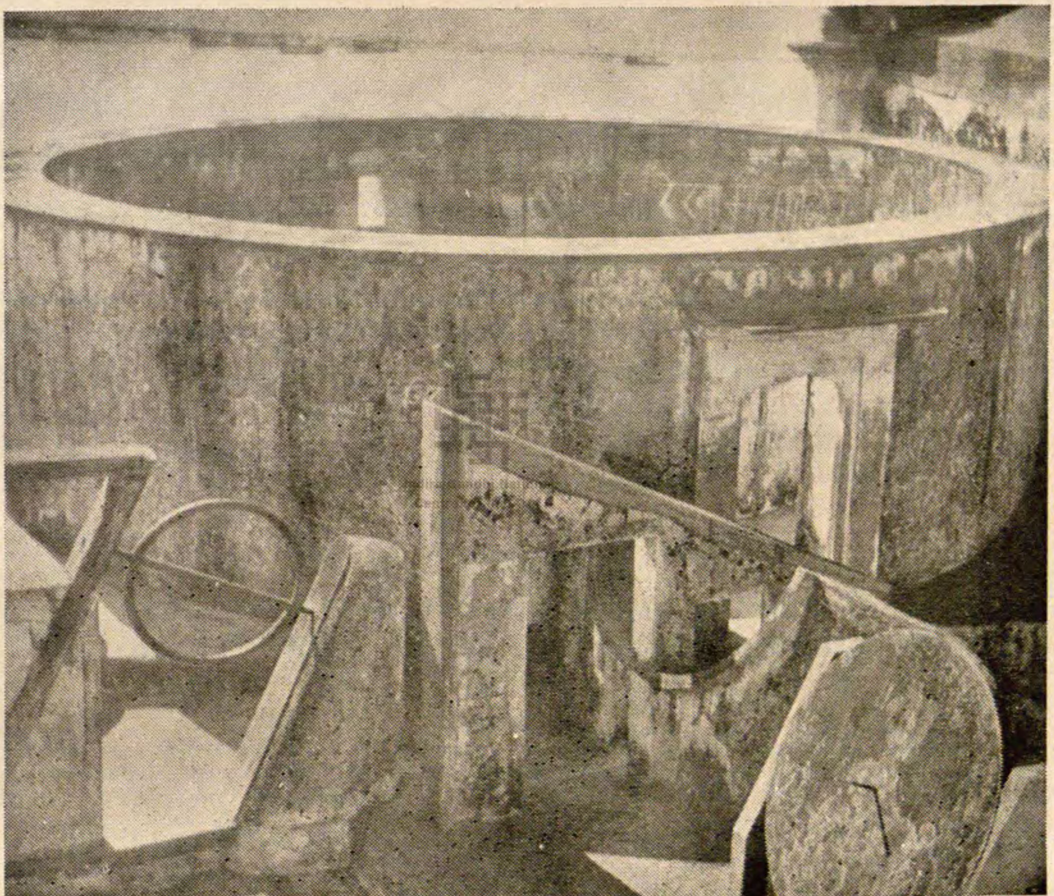
Pl. 50 The Delhi Observatory : View from the Gnomon



Pl. 51 General View : The Jaipur Observatory



Pl. 52 The Ujjain Observatory



Pl. 53 The Varanasi Observatory over looking the holy Ganges